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CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY
(Former Mines Branch)

THE CONTRIBUTION OF SCIENCE AND TECHNOLOGY IN THE MINING, PROCESSING AND UTILIZATION OF MINERALS IN ASSURING AN ADEQUATE RESOURCE BASE FOR CANADA

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ABSTRACT

The evaluation of Canada's mineral resource base involves the estimation of not only the size, quality and distribution of mineral deposits, but also of the proportion of these deposits that are economically recoverable now and in the future. No one will deny the importance of technology in making it possible to extract a mineral deposit economically and thus convert a resource into an assured reserve. It is important, then, in the development for the mining and metallurgical industry to identify constraints to the development of our mineral industry that may be solved by technological innovation.

This publication identifies major technological problems in mining, the processing of ores, concentrates and metals, and the utilization of mineral-based materials. The various technological gaps in the total system are summarized so as to illustrate the impact on mineral policy development of science and technology deficiencies. This is done by relating technological needs to various imperatives identified in the mineral policy review document "Towards a Mineral Policy for Canada - Opportunities for Choice" published in 1975 under the authority of the federal and provincial ministers responsible for mineral policy.

RESUME

Une évaluation de la base canadienne en ressources minérales implique une estimation non seulement de la dimension, de la qualité et de la distribution des gisements de minéraux, mais aussi de la proportion de ces gisements, qui sont économiquement récupérables maintenant et dans l'avenir. Personne ne peut nier à quel point la technologie est importante pour rendre possible l'exploitation économique d'un gisement minéral et ainsi convertir une ressource en une réserve sûre. Alors, il est important d'identifier, dans le développement pour l'industrie minière et métallurgique, les problèmes que le développement de notre industrie minérale comporte et qui peuvent être résolus par des progrès technologiques.

Ce rapport identifie les principaux problèmes technologiques dans l'exploitation, le traitement des minerais, des concentrés et des métaux et dans l'utilisation de matériaux à base minérale. Les différentes lacunes technologiques du système en entier sont résumées afin de pouvoir illustrer l'impact des déficiences scientifiques et technologiques sur le développement de la politique minérale. Cette illustration est donc faite en établissant un rapport entre les besoins technologiques apparentés et les différents impératifs identifiés dans le document de révision de la politique minérale Towards a Mineral Policy for Canada - Opportunities for Choice, publié en 1975 sous l'autorité des ministres fédéral et provinciaux responsables de la politique minérale.

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1.0 INTRODUCTION

Early in 1971, the provincial and federal governments began working jointly on the development of a national policy for minerals other than fossil fuels. A goal and set of inter-related objectives as a basis for formulating mineral policy were identified in the first phase of this intergovernmental activity. These were presented in the document "Mineral Policy Objectives for Canada" published in mid-1973 under authority of the federal and provincial ministers responsible for mineral policy.

The second phase of the deliberations resulted in a second document entitled "Towards a Mineral Policy for Canada - Opportunities for Choice", also authorized by the ministers at a meeting held in late 1974. Four basically different approaches to how minerals should best contribute to Canada's social and economic development were identified. These were:

a) to encourage maximum mineral production (the status quo)
b) to encourage increased diversification through increased processing and mineral-based manufacturing in Canada
c) to promote highest possible financial returns to Canadians from minerals
d) to conserve mineral resources for long-term domestic needs.

Because of fundamental differences between them it was concluded that only one should be selected as the dominant theme if an effective policy were to result.

The policy that finally emerges will be a melding of a number of government programs at both the federal and provincial levels. The implementation of mineral policy will require the wise use of elements of taxation, export-import, regional development, and science and technology programs. Consequently, the third phase of the mineral policy review is concerned with demonstrating how these various elements can contribute to policy implementation. This paper deals with the potential impact of science and technology, or their lack, on the advancement of national goals.

In the context of mineral policy implementation, science and technology are tools or means to the end, and not ends in themselves. To determine the importance of science and technology as means of attaining the national objectives, it is first necessary to specify those areas where technological innovation can contribute to the advancement of objectives and then assign priorities on the basis of the objectives.

The Canada Centre for Mineral and Energy Technology (CANMET) dealt with the problem of identifying where science and technology can implement mineral policy by studying the mineral-based system from the viewpoints of operations and commodities. This was necessary because mining technology is not constrained by the commodity being mined but instead by technological gaps in such operations as drilling, blasting, materials handling and ground support. On the other hand, technology for the processing of minerals from mine ore to metal rests on the physical and chemical properties of the commodity involved whereas efficient utilization of mineral products and metals depends on both the properties of the commodity and the capabilities of such operations as rolling, casting, forging, and welding used to make marketable semi-finished products.

This report presents the results of CANMET's study under the headings of mining, processing and utilization. Activities concerned with the exploration for, and discovery of, minerals were not considered, while activities required to produce semi-finished products from metal were studied under the utilization heading.

The research was conducted keeping in mind the objectives outlined in the two documents covering the work of the mineral policy review to date. Areas where new technology could encourage increased domestic processing of ores and concentrates were specified. Gaps in the technology required for improving the

working and natural environments, and for increasing the capability to recycle scrapped material were also identified. The need for improved technology to broaden the mineral resource base by increasing recovery and making lower-grade and more complex deposits economic, and to reduce dependency on foreign sources for some mineral products were important considerations. Technological innovation implies greater efficiency and lower cost. Consequently, energy conservation is an important aspect of technological improvement and used in this study as a criterion for assessing the need for new technology.

There is no implication of assigning priorities in presenting this report since that will be provided by the yet-to-be enunciated policy. However, regardless of the policy chosen, certain issues requiring technological innovation will have high priority. These will include worker and public safety, protection of the natural environment and security of supply.

2.0 SCIENCE AND TECHNOLOGY REQUIREMENTS FOR THE MINING SYSTEM

2.1 Introduction

The current gross value of Canada's mineral output is about $6.4 billion annually. Of this, over $4 billion comes from the production of non-energy minerals. In turn, more than 60% of output is exported, or about 25% of Canada's total exports. The mining industry in Canada has been able to achieve its present economic importance by providing secure, long-term supplies of minerals and concentrates at competitive prices, despite a growing dependence on low-grade, mineralogically complex ores.

Although many of Canada's rich mineral deposits have already been or are in the process of being worked out, the country is still endowed with a very substantial resources base. Indeed, as Fig. 1 shows, Canada has more than 100 underground mines - a larger number than any other country in the Western World - and is second only to the United States in open pit mines currently in production.

The world demand for minerals and metals continues to grow apace. To meet this, some economists have predicted that output in Canada will triple by 2000 A.D. Yet, although the resource base may still be considerable, in addition to becoming increasingly lean and more complex mineralogically, ore deposits are becoming less and less accessible. In international markets, the minerals industry in Canada faces stiff competition especially from mining operations in the less developed countries where determined efforts are being made to attract investment capital. Mining companies operating in these countries are likely to enjoy a competitive edge in the form of lower labour costs, favourable land acquisition arrangements and relaxed environmental protection regulations.

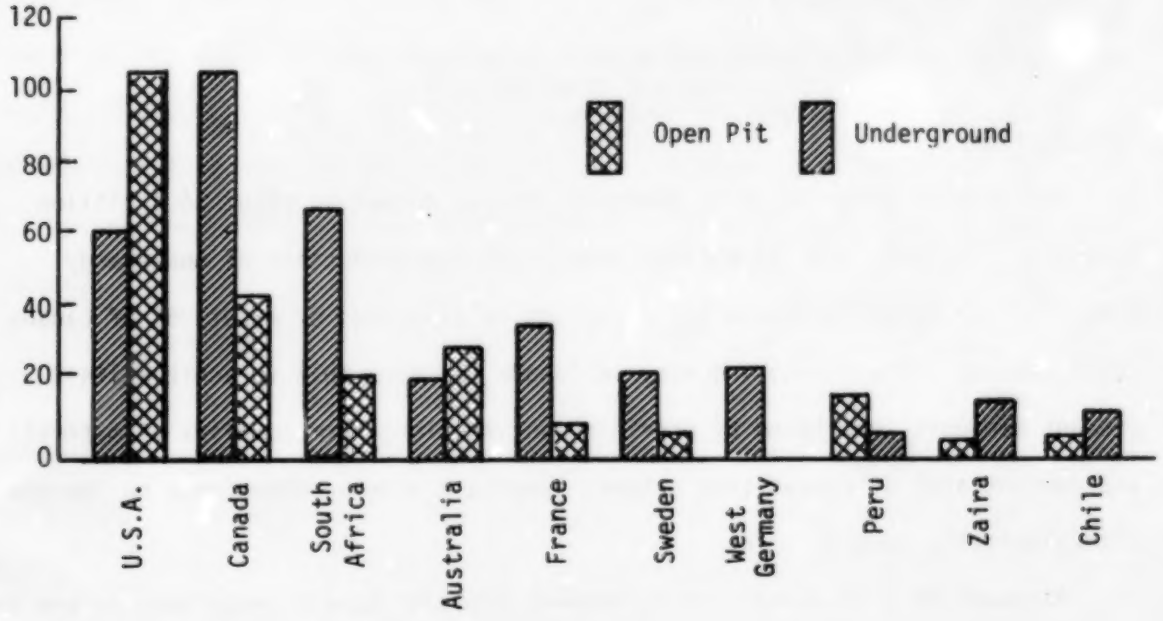

Fig. 1. Analysis of Mines Producing More than 150,000 Tons of Ore per Year. (Non-Coal).

Forecasts that a three-fold expansion in mineral production may take place are based on an awareness that, while the quality of mineral deposits being worked is declining progressively, the quantities of useful mineral commodities and metals available at each successively lower level of concentration appear to increase - often sharply. This means, for example, that there should be much more copper available at a grade of 0.5% than at 1.0%, more iron at a grade of 35% than at 40%. Thus, broadly speaking, for the immediate future, Canada's economic mineral reserves are more likely to be limited by the nation's ability to mine, process and market ores and concentrates competitively than by the physical extent of the ore bodies.

While competition from abroad is stiffening, at home, expectations generally are rising and attitudes are changing towards work considered unappealing and hazardous. This translates into a serious shortage of people prepared to work in mines. Two courses of action are open. Steps will have to be taken to improve safety, and to make mines generally healthier and more attractive places to work. Processes must be automated to compensate for the manpower shortage and to reduce the arduousness of working at the mine face.

The prospect is a challenging one. Not only must productivity be increased to the point that lean ores can be mined and marketed competitively with those from overseas, but money must be found from earnings to improve working conditions as well as to take the measures necessary to meet environmental regulations.

Concern for degradation of the environment begins with questions of land use, but assuming that mineral production is accepted as a legitimate use of land in most regions, Canadians will expect that mining activities be carried

out in ways which minimize other environmental impacts. Although the effect of mining operations on the land may be quite localized and, in general, may eventually be subject to acceptable restitution, the off-site effects in terms of water quality may be widespread and objectionable. Ways must be found to minimize and control these undesirable consequences.

By world standards, the mining industry in Canada is vigorous and large. We may expect it to take the lead in solving many of its own technical problems.

The problems which face the industry are allied more with the mining as such than with the particular commodity being mined. For example, health hazards result mainly from the respirable dust containing quartz rathen than with the nature of the minerals recovered. Equipment used in underground mines is essentially the same throughout the industry, as is also the equipment used in open pit mines. Again, a new development in hard rock mining methods would be equally applicable to nickel, copper, zinc or lead. Tailings disposal problems originate with the presence of sulphide in the tailings and have little to do with the mineral being mined. Other examples abound. Thus, discussion in the following pages is organized on what is known as a process basis, rather than on mineral commodities.

2.2 Open Pit Mining

Approximately two-thirds of the tonnage of minerals mined in Canada comes from open pit mines. About 40% of the copper, over 50% of the zinc and lead, and almost all of the iron ore and asbestos produced in Canada come from open pits.

During the past decade the development of large scale mining and hauling equipment has made it economically feasible to work lean ores from very large pits. But as the scale of operations increases, so does the economic significance of a number of problems. Among these is the matter of pit-wall slope. From the point of view of safety, the slope of pit walls should be as flat as possible to eliminate the risk of collapse. From an economic point of view the pit walls should be as steep as possible. Thus, for a large open pit, a change in slope angle of one degree can alter the quantity of waste rock to be excavated by as much as 20 million tons, which corresponds to a cost of about $10 million.

However, long-term comprehensive studies will be necessary before it is possible to design rock slopes with similar accuracy to that possible with soils. If the studies are to be aimed at placing open pit design on a sound engineering footing, a great deal of basic information and operating data will have to be assembled for the number of factors which must be taken into account. With these data, it should then be possible to resolve in a systematic way and at minimum cost, the conflicting demands of operational efficiency and maximum ore recovery with an assurance for the safety of workers.

Studies should include an assessment of geophysical techniques used for site investigation and should identify the geological parameters to be measured. Both laboratory and in-situ methods of measuring the strength properties of rock formations and structural discontinuities whould be evaluated. The modes of occurrence and the effects of ground water and slope stability should be assessed, as should methods of drainage and their costs. Where possible, these studies should be backed up by case-history analyses of pit slope failures.

Other investigations in the program should be directed to evaluating the effectiveness of perimeter blasting techniques to improve slope stability. Artificial support systems need to be evaluated in full-scale field trials and instrument systems must be developed and tested for monitoring wall rock movements as they occur during mining. The purpose of monitoring is to anticipate impending failures. Finally, in addition to developing analytical methods for pit slope design, studies should be carried out for planning waste disposal and reclaiming tailings dams, and basins.

Much of this work is already in hand in a coordinated program administered by federal laboratories. It is partially funded from the Federal Treasury but involves universities, consultants and mining companies alike. When it is complete, the results of the studies are expected to have a widespread impact on the industry.

2.3 Underground Mining

Almost all of the nickel, potash and gold, 60% of the copper, and about 40% of the zinc and lead in Canada are produced from underground mines.

As the more readily accessible ore deposits are worked out, there is a trend to working at greater depths in underground mining. Although accessibility is usually thought of in terms of latitude and longitude, a deposit which is two miles deep is also remote because of the technical difficulties that have to be overcome to mine it.

The deeper the mine, the more intractable are the difficulties with ground control generally, and with rock bursts in particular. To cope with them it is necessary to use more expensive methods of mining such as cut-and-fill.

As shown in Fig. 2, the costs of underground mining are significantly higher than those of open pit mines. Thus the minimum ore grade which can be profitably mined (the cut-off grade) is significantly higher in an underground mine than in an open pit mine. More efficient and cheaper underground mining methods would enable lower ore grades to be recovered effectively increasing reserves. Indeed, across the whole sequence of metal mining and processing operations, in general the greatest potential for increased recovery does not occur in the concentrating, smelting and refining stages, but in mining.

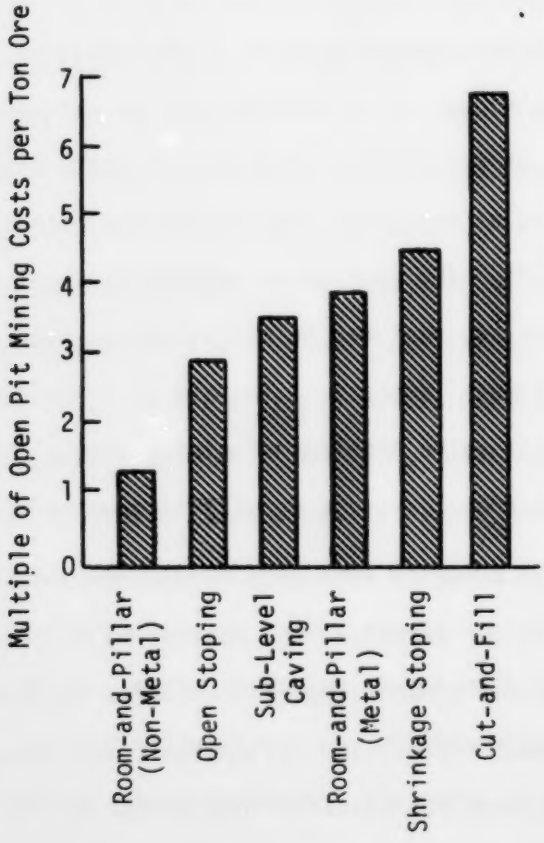

Fig. 2. Costs of Various Underground Mining Methods

The objective of research in underground mining is to improve existing methods and to develop new ones for mining under difficult ground conditions, particularly at depth. Cut-and-fill is the principal underground method; it is capable of almost 100% extraction and is virtually the only one used below 4000 ft., especially in poor ground conditions. But it is also very expensive.

In other mining methods, a major problem is to improve current techniques for pillar recovery which can constitute as much as 60% of the orebody. Inability to recover pillars will mean a significant reduction in the mineral resource base.

In the continued search for cheaper methods, investigations are underway to determine whether the techniques of bulk mining can be extended to greater depths. Bulk mining increases productivity and reduces costs because large volumes of ground are blasted at one time. At present the method is restricted to depths of less than 3000 ft. The problem of extracting metal values from mines where ground conditions are poor has helped stimulate studies of in-situ leaching of uranium and base metal deposits. The aim is to eventually develop techniques which not only will solve problems of mining safety, but will allow metal values to be recovered from low-grade deposits economically.

Rock falls are the major cause of accidents in underground mines. The future development of systems for detecting and monitoring hazardous ground conditions coupled with improved ground support structures would contribute greatly to safety of the labour force. The systematic trend towards mining at greater depth highlights the need for research into better mining methods and support systems. This need lends itself particularly well to cooperative programs between the universities, federal laboratories and mining companies.

Finally, there are opportunities to improve the efficiency of underground mining by doing operations research with computer models. We might expect such studies to indicate deficiencies in existing systems and to signal fruitful areas for further study.

2.4 Mining Equipment

Many of the improvements in mining productivity during the past decade have been due to the introduction of new equipment or to an increase in the size of existing equipment. In some underground mines, raise borers have increased productivity and safety by eliminating the manual driving of raises. Scooptrams have helped to cut the costs of moving rock and at the same time have added an operational flexibility that has enabled mining methods to be changed and improved. Other examples include: machines for mining Saskatchewan potash continuously and for drilling larger holes to greater depths, power shovels, draglines and trucks moving 100,000 tons of rock per day.

The quest to improve current mining and hauling equipment and to find new ways of breaking and transporting rock will continue. As a result, we may expect that costs will be cut, productivity increased, physical labour reduced and, in general, safety improved. Indeed, the mining industry, including oil and gas, already devotes about $400 million annually to new machinery which is purchased from foreign sources. Whereas there is no evidence to suggest that it has so far not been to Canada's advantage to import new technology in mining equipment, the country may well be in a strong position in the next decade to begin performing its own R ard D. Consistent with recent Cabinet policy, it should receive every encouragement to do so. But at present, the majority of Canadian-owned mining equipment suppliers have neither the engineering capability nor the financial resources to undertake multi-million dollar development programs. Parenthetically, it might also be noted that Canadian subsidiaries of foreign-owned mining supply companies do not carry out very much R and D in Canada either.

However, if the premise is valid that the mining industry is essential to the economic well-being of the country then, perhaps, the federal government ought to consider some form of support at an adequate level for mining machinery development. On the other hand, corporately, the mining industry in Canada is large and its long-term business prospects appear good. The time seems appropriate, therefore, to initiate discussions on the possibilities of cooperative R and D ventures. The forum for such discussions already exists in the National Advisory Committee on Mining and Metallurgical Research.

Mechanical methods will play an increasingly pre-eminent role in mining. If the industry is to remain competitive, work should be undertaken towards the eventual goal of developing a system for mining hard-rock ore bodies and for delivering rock to the main haulage way. Where necessary, these systems should be capable of operating on steeply dipping and irregular veins and, ultimately, should be fully automated. However, before even a first generation system can be put together, considerable development work has to be carried out on the three basic elements - the hard-rock mining machine, the conveying equipment and the sensors.

Ore haulage is another area where new technology can increase efficiency. Haulage costs account for about 30-50% of mine operating expenses, and even modest improvements over the performance of current transportation methods can result in useful dividends. For example, methods of hoisting ore in skips up mine shafts have not changed significantly in 50 years. However, based on experience in solids pipelining, drawn mostly from work on dredges, some preliminary tests on hydraulic hoisting indicate this new method of transporting ore through large vertical lifts is technically feasible. The prospect of being able to replace the intermittent delivery of ore to the surface with a system

for continuous delivery is attractive. Similar considerations provide the impetus for further development work on steep-inclined conveyors for hauling rock out of open pits. Here the batch delivery system to be replaced is the large truck.

Technology can help improve efficiency and increase output in other ways. For example, in equipment design, the further use of automatic controls will not only lead to better machine performance, but will also reduce delays arising from breakdowns. In underground mines, Canada has lagged behind Europe in exploiting the benefits of communication networks. These enable operations throughout the mine to be monitored and controlled centrally. The systems are important for minimizing delays when equipment breakdowns do occur, and are vital to ensuring a prompt response to emergencies.

2.5 Underground Environment

The popular image of a miner's life is hardly an inducement to recruiting. In part it helps to explain the shortage of miners in a period of high unemployment. One solution lies in trying to improve underground working environments. The same objective is shared by regulating authorities who are setting higher standards for ventilation and for dust, noise, fumes and emission controls. Indeed, the consensus in industry and government is that research on improvements in the working environment of mines should receive the highest priority.

One important objective in any environmental improvement program is to upgrade air quality. Atmospheric pollution which is injurious to health can occur in a number of mining and milling operations. For example, prolonged exposure to dusts can lead to respiratory diseases of which silicosis, arising from the chronic inhalation of fine quartz particles, is possibly the most serious. Similarly, the role of fine asbestos dusts in the occurrence of

asbestosis has been well documented for many years. Moreover, recent work has related the inhalation of asbestos to cancer, particularly to a previously rare malignancy known as mesothelioma. Not all respiratory hazards however are quite as baleful as some mineral dusts. Emissions from diesel engines are an example. These are a source of pollution which are on the increase as mechanization and the size of mining equipment grows. But the electrification of mining equipment would go a long way towards eliminating this nuisance. Blasting fumes too are noxious but for the time being mines will continue to depend on ventilation for their control.

The conventional approach to pollution abatement has been simply to dilute pollutants by increasing air displacement through the ventilation system. A more systematic solution would be for each mine to have a detector network to monitor pollutants on a continuous basis. The data collected could be used to construct models indicating important sources of pollution, distribution of pollutants, and the effect on the distribution of changes in ventilation. Information would then be available to engineer changes in the ventilation system in the most effective way.

As underground mines become progressively deeper and hotter, fatigue is likely to become a serious problem unless air refrigeration is installed and some mining practices revised. While the thermal gradient varies from one part of the country to another, it is roughly 0-50°C per 100 feet. Rock temperature in some mines at 7000 ft is between 40 and 45°C, and humidity from water used to transport backfill adds significantly to the discomfort engendered by the heat.

Even in such simple matters as clothing and illumination there is scope for improvement. Indeed, there is a pressing need for more practical and comfortable wearing apparel, including a comprehensive heat protection unit. These have

changed little in the past 25 years, although steps have been taken recently by the industry to finance a program aimed to remedy the situation.

2.6 Waste Disposal

At most mines only a small percentage of the excavated ore and rock leaves the plant in the form of a concentrate, mineral or metal. The balance is waste, and is usually disposed of on surface, although mines which use backfilling methods can often return as much as 50% of their tailings underground.

In general, the waste is pumped as a slurry from the mill to a dyked disposal area or tailings pond. The wastes are likely to contain flotation reagents as well as significant quantities of rock particles which can be chemically active. Although slurries are usually "neutralized" before they are discharged into a pond, leaching of chemically active waste material will continue long after the waste has been dumped. Some of the effluent is lost by evaporation but most of it decants into a drain and flows from the pond into the local water courses. It must be monitored and further neutralized if necessary before it finally escapes. Tailings from base metal mines contain sulphides which oxidize and acidify the effluent presenting particularly persistent problems in this respect.

Containing and controlling the effluent from a tailings pond also poses problems. Although the basin or pond embankments may be maintained in good condition, heavy rains, or spring run-off can lead to overflowing and erosion. The task of controlling effluent from disposal areas is compounded in mountainous regions and in the north. In mountainous regions, ponds may be located on inclined terrain, and in the north, they may be subject to permafrost heaving. In either case, breakouts can occur, particularly during spring. In most of Canada, winter reduces the time available for fine particulates to settle. Indeed, especially in the north, tailing ponds may be frozen for eight months or more each year. As a result, when spring comes and the effluent finally does start to flow, it may not conform to water turbidity standards.

When a mine is no longer active, the disposal area has to be stabilized and sealed off with self-sustaining vegetation. This should be done in a manner that will prevent continued water seepage, is aesthetically pleasing and will allow the land to be restored to other uses. Again, the north poses particular problems with the brevity of the growing season adding to the difficulties that exist elsewhere in the country of eastablishing a viable plant cover.

Although the tailings from most mining operations are wet when dumped, asbestos wastes are dry. The practice leads to dusting in the general vicinity which constitutes a health hazard, the significance of which is only just beginning to be fully recognized. In contrast to sulphide tailings, asbestos wastes are very alkaline and this too presents its own peculiar difficulties when it comes to establishing self-sustaining vegetation on abandoned dumps.

For these reasons, therefore, the management of mine wastes, waste water treatment and revegetation are considered important areas for continued research.

3.0 SCIENCE AND TECHNOLOGY REQUIREMENT FOR THE PROCESSING OF ORES, CONCENTRATES AND METALS

3.1 Introduction

While Canada's capacity for smelting, refining and other forms of processing has grown in the last twenty years, it has not done so at a pace commensurate with the increase in the export of unprocessed minerals. Notwithstanding policy initiatives aimed at securing expanding industrialization and employment from the processing of minerals, proportionately, we have actually lost ground and continue to do so.

In response to this situation, Cabinet has recently directed that the development and implementation of mineral policy should stress "industrial development and diversification". Consistent with this decision, an earlier directive in 1973 gave the Department of Industry, Trade and Commerce a mandate to coordinate federal and provincial efforts to promote the further processing of minerals where these initiatives would lead to finished or semi-finished products competitive on international markets. Although the intent of this program will be limited to executive and, where necessary, to legislative action, success in implementing the policy must result in increased demands in the private sector for engineering processes and hardware of many kinds.

Undoubtedly, some opportunities for profitable business ventures need only draw on current state-of-the-art methods and technology. But others will not succeed in the face of international competition, no matter how proficiently they are managed, without new methods, new systems or new technology in some form or another exclusive to Canada. Although there may be exceptional circumstances in which these requirements could be purchased on a "turn key" basis from outside the country, in general, they should be developed in Canada.

Moreover, to prepare for the day when mining is no longer able to make the contribution to the national economy that it does at present, Canada must work towards a more comprehensive industrial maturity. To this end, there are a number of technical challenges facing the industry at present which, based on past performance, it may be expected to meet. Compared with the performance of other major industries, the record seems good.

According to an internal survey made by the Ministry of State for Science and Technology in 1973, of a total of approximately $68 million spent on R and D in the minerals industry sector, about 60% was paid for by the industry itself, while rather more than 70% was actually carried out by the industry. The balance was either funded from federal resources or performed in federal laboratories. If expenditures on R and D related to exploration are included, the total rises to about $120 million which is 2% of the $6 billion contribution the industry makes to the G.N.P. By comparison, the forestry industry contributes about 50% to the cost of R and D in that sector, while agriculture contributes less than 10%, and the fisheries industry virtually nothing.

A 60% contribution by industry to R and D expenditures which represent about 2% of the revenue generated by the industry, are performance indicators recommended by the Senate Special Committee on Science Policy chaired by Senator Lamontagne.

In 1972-73, the federal contribution to the mining industry as a whole amounted to approximately $25 million. Of this, about 10% was spent in support of mining research per se, 40% on processing research and about 50% in fabrication and utilization. An analysis of the costs of extracting metals from sulphide ores, for example, indicates that the costs of processing and smelting represent about 80% of the total costs for an ore mined from open pits, whereas, in underground mining, processing and smelting costs account for about 60% of total costs. Thus a comparison suggests that if R and D in the processing sector receives about four times the federal funding as mining, it is a distribution that is to some extent disproportionately weighted in favour of processing.

Evidently, the key to the future of the mining industry in Canada is technology, or rather, better technology. Better technology can increase reserves, improve recovery efficiencies and improve competitiveness; it can provide the tools for better waste management practices, provide additional opportunities for adding value to minerals before export, and develop openings for business in consulting and equipment sales.

Problems in mining tend to be characteristic of the mining process per se, and transcend the nature of the minerals being mined. In processing, the chemical and physical properties of the ore are important; they determine the form of the processes used to extract the mineral values and underlie the nature of the problems which occur. Thus, it is convenient to arrange the passages which follow on a commodity basis.

3.2 Iron and Steel

For its combination of strength and other physical properties, together with a price that cannot be matched by other metals, steel is a corner-stone of modern society. In 1973, world production of steel amounted to about three quarters of a billion tons of which Canada's share was approximately 14.5 million tons.

At present, almost all steel is made by refining a metallic charge of iron from the blast furnace, or recycled steel scrap, or often, some mixture of the two. However, steel can also be made using pre-reduced sponge iron pellets as a feed stock. In some circumstances, this method has advantages and it will become increasingly important in the future, but at the moment less than a quarter of a million tons of steel are made this way annually in Canada.

As an ingredient for making steel, iron accounts for about 70% of all steel production. Iron is made in the blast furnace by reducing iron ore with metallurgical coke made from coal. Thus, iron ore and coal are the two basic mineral commodities for creating new steel.

In addition to its resources of many other minerals, Canada is fortunate in being endowed with large reserves of iron ore and coal suitable for making metallurgical coke, although they may not necessarily be located close by. In 1973, Canada produced about 48 million tons of iron ore of which about 10 million tons were used domestically and 38 million tons were exported. In the same year, more than 11 million tons of coal were exported from Western Canada to Japan for making metallurgical coke while almost 8.5 million tons of coal were processed in Canada to make slightly more than 6 million tons of coke for domestic use.

Of the coal used in Canada for making coke, less than 1 million tons comes from Canadian mines, the balance being imported from the eastern United States. For several reasons, these supplies are no longer as secure as they once were and Canada will need to turn more and more to its own resources.

Happily, there are extensive deposits of coking coals in the Rocky Mountain regions of Alberta and British Columbia which have not yet been committed or developed. The chances are that blends of coals from this area will produce acceptable cokes, but considerable evaluation and testing will be required to confirm this. In contrast to the coking coals mined in Cape Breton, these western coals are low in sulphur but, in general, the more accessible coals contain undesirable amounts of mineral impurities. These impurities are very finely dispersed, and if the coals are to be upgraded, new methods will have to be worked to achieve good recovery during beneficiation and for the process to be economic. In addition both the mining of deposits in a mountainous region which, in general, will be geologically folded, and the shipping of the coal to the steel mills in Eastern Canada are costly. It becomes apparent that, although Canada may be able to count on abundant supplies of metallurgical coke in a world where this is becoming a dwindling commodity, the supplies are unlikely to be cheap.

3.2.1 Iron Ore

A strong domestic steel industry must be an objective of any national program aimed at fostering industrial development and diversification. Indeed, industrial maturation in many other sectors will be immeasurably abetted by a flourishing steel industry in Canada.

While it is anticipated that the Ontario heartland of the steel industry will develop systematically, there are at present a number of plans and proposals for new and expanded steel production facilities which, in response to economic and political forces, accentuate a trend towards regionalization. In concert with this trend, "local" iron ore deposits should be evaluated for the potential economic advantage they may offer in the form of proximity to raw materials, consistent with their geological setting and the technological limitations of exploiting them. The long term national need to prepare for future growth by carrying out natural resource evaluations is an added reason for undertaking this work.

Of the known ore reserves which at present are reasonably accessible, only a small proportion - approximately 10% of the ore in the Labrador Trough, for example - are "direct shipping" grade; that is to say, are suitable for ironmaking without some form of beneficiation. In fact, viz-a-viz ore deposits in many other countries, the average iron content of Canadian ores is low. Of itself, this is not necessarily a serious economic disadvantage, providing the iron can be readily concentrated and the technology to do so is available. Such is the case, for instance with the specular hematite in the southern areas of the Labrador Trough. But if, as well as being low in iron content, an ore is complex mineralogically, as for example, the titaniferous magnetites of Quebec and Ontario, or the deposits on the Peace and Snake Rivers, viable commercial development may have to wait many years until more easily exploited reserves elsewhere have been exhausted.

Most of the iron ore produced in Canada is mined in Newfoundland (Labrador), Quebec and Ontario and about 80% of it is exported as concentrates or pellets.

Of ore bodies not yet developed, the magnetite deposits in the Lake St. Joseph region of northwestern Ontario assay about 27% iron. Although the grade is low, the region is conveniently located close to the Great Lakes area, and the deposits respond very well to conventional concentrating techniques. Thus, of the undeveloped iron-bearing resources, these appear the most promising. Indeed, so thoroughly can the gangue be winnowed out of the ore that the resulting concentrate is suitable as feed for the manufacture of directly-reduced low silica metal pellets.

In the long-term, increasing difficulties are expected in securing good recoveries with the present methods of concentrating the hematite in the Labrador Through. As mining operations move progressively north, the hematite becomes less and less metamorphosed and thus finer and finer in grain size. To deal with this problem current beneficiation technology will have to be modified. However, the problem is not expected to become pressing before the end of the present century.

The geological and mineralogical characteristics of an iron-bearing deposit will determine the sequence of processes that are necessary to extract iron from it and refine the iron into steel. If the characteristics are such that steel cannot be made from an ore by some combination of existing techniques or processes, then new processes will have to be developed before mining can be contemplated. This exercise may involve developing a new method, and the equipment to go with it, for a single step in the series of processing stages necessary to make steel, or it may be that a number of steps must be completely revised.

In parts of Ontario and Quebec there are extensive deposits of an iron-bearing ore known as titaniferous magnetite. These contain as much as 44% iron and up to 2.5% chromium. But they also include various quantities of aluminum, vanadium and, as the name implies, titanium. To assure profitability, it is hoped also to recover the vanadium, chromium and aluminum in the form of marketable oxides.

Assuming that an economic steelmaking process can be developed, these deposits could constitute the basis of an export oriented regional industry since abundant electric power will be available from James Bay for smelting. The economics of producing iron and steel relate essentially to the cost of assembling raw materials and energy and the fact that these ores are self-fluxing is an advantage. The titanium present in the ore reports in the slag, but at the moment, in the face of competition from ilmenite slags from Sorel, the titania content is too low to warrant recovery.

The concept of an integrated steel industry in Western Canada has thrown the iron-stone ores in the Peace River district of Alberta into sharp focus. But at present, they are a delight only to the research worker who perceives in them a challenge to his ingenuity. These ores contain about 30% iron but they also include large amounts of silica in a very complex mineralization which precludes adequate beneficiation by conventional means. Thus, the result of trying to smelt this material in a blast furnace would be a non-self-fluxing feed producing a very large volume of slag. Although a number of European countries have smelted iron-stone ores for many years, all have progressively switched to cheap high-grade concentrates available in abundance on world markets.

The deposits in Alberta contain about 1.5% phosphorus. To produce steels of acceptable quality, phosphorus must be reduced to a very low concentration.

However, new technology exists for dealing with high phosphorus irons, and the slag it produces could have value as a fertilizer material. In many places, the deposit is near surface, but although the overburden to be removed may not be very large, the deposit itself is only about 10 feet thick. Several different approaches are being considered for developing economic steelmaking processes based on these ores, including the reduction of pellets with Albertan sub-bituminous coal in short-shaft electric furnaces.

The performance of the blast furnace has been improved systematically over a period of many years to the point that today it is a very efficient tool for reducing iron ore to iron. To achieve this performance, it has been necessary to control operating variables closely. One of these variables is the size distribution of the iron ore charged to the furnace. The iron ore lumps should be uniform in size and free of fines so that the reducing gas generated by the combustion of coke can circulate readily throughout the charge.

In Canada, less than 3% of the ore charged to the blast furnace is of direct shipping grade. The balance is agglomerated; about 80% of it as pellets and the rest as sinter.

Pellets are usually produced at the mine site and are made by mixing iron concentrates with a few per cent of a bonding clay (bentonite) imported from the United States and drying in oil or gas fired equipment. Sinter is made at the steel mill by mixing iron concentrates with dusts from the blast furnace and steel-making furnaces together with coke fines, and firing this agglomerate on a travelling grate until incipient fusion occurs. The sinter is then crushed to size before charging to the blast furnace.

Most of the heat necessary for producing sinter is supplied by the in-situ combustion of the coke fines but there is usually plenty of by-product gas available at a steel plant to meet the auxiliary heating needs of the process. On the

other hand, as already pointed out, oil or gas must be used for drying pellets. At some mine sites energy costs for oil in particular are already significantly in excess of energy costs for electricity. But cost differentials apart, the future security of electricity appears far more reassuring than the future of oil and gas supplies, particularly where there may be a reliance on off-shore sources for the latter, as there is in some eastern mining operations.

Thus, until nuclear steelmaking begins to make its debut, a trend can be expected towards the use of electricity for drying pellets and a greater emphasis placed on the use of sinter, although the environmental impact of sinter-making processes will need some attention.

3.2.2 Steel

The winds of change prevail on the steel industry. They start at different points, but they unite to propel the industry in a direction which, although it may ultimately fall short of continuous steelmaking, will at least lead to greater continuity in the sequence of steelmaking processes.

The impetus originates from two main sources. First, the need to minimize the energy consumed in making steel and to change the "energy mix"; second, the advent of pre-reduced sponge iron pellets as a source of iron units for steelmaking.

The imperatives of the current world energy situation will exert an overriding effect on the course of events in the steel industry during the next 25 years to the point that it is unrealistic to discuss future science and technology needs without taking these considerations into account. Indeed, the industry itself attaches sufficient importance to energy matters that, in an unusual move, it has formed an association for the purpose of undertaking cooperative studies on selected energy topics. The federal government provides a secretariat with observer status.

The iron and steel industry in Canada is a very large consumer of energy. The energy from all sources that goes into making one ton of steel is roughly equal to the heat available from burning one ton of coal. Thus, the energy consumed by the industry in producing 14.5 million tons of steel amounts to about one twentieth of the energy used for all purposes in the country.

No less than other sectors of society, the steel industry is conscious of the need to conserve fuel but its present practices and plant represent an optimization of costs in an era when energy was considerably cheaper and seemingly, much more plentiful than it is now. But the dramatic events which began with the October War in 1973, call for a reconsideration of energy consumption practices and, in particular, of ways in which fuel costs can be reduced. There are several options.

First, it should be possible to reduce fuel consumption by improving the thermal efficiency of existing processes. For example, there will be a number of opportunities to extend recuperative heating practices.

Second, in some cases it should be possible to change from one existing process to another where the switch results in a reduction of energy demand. An obvious instance here is offered by the contrast in the amount of fuel consumed by the traditional open-hearth steel-making furnace and the already widely used but newer basic-oxygen furnace. Recent developments on the BOF have simplified equipment and reduced capital expenses. At the same time, the operating characteristics have been improved and the yield of each heat has been increased by about 2%, although the life of the furnace bottom lining has suffered.

A third course of action is to reduce the present dependency on oil and gas by revising processes in favour of using coal or electricity*. In fact, financial

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*It is assumed that the electricity will be generated by hydro-power or nuclear reactors.

savings apart, current uncertainties about long-term supplies of oil and gas are themselves sufficient reason for considering the switch. Prime targets are oil injection in blast furnaces and oil and gas consumption in pelletizing processes.

Present thinking is that it should be possible to reduce the total amount of energy expended to produce a ton of steel to about 17.5 million British thermal units. This represents a saving of rather less than 10% viz-a-viz best current practices and illustrates well the fact that the industry is by no means profligate in its present use of energy. However, changes cannot be made overnight. New plant and equipment on the scale of steel company operations are costly and the industry will want to maximize its returns on any capital investment. Before embarking on new investment programs, therefore, cooperative studies on whole system models are likely to be undertaken to identify sites of greatest heat loss and to provide guidelines for plant and process revisions.

Comparable to its needs, Canada, of course, has greater indigenous fossil fuel resources than most other industrialized countries, but this could work to the nation's eventual disadvantage in steelmaking technology. Steelmakers in many parts of the world are studying the possibility of using nuclear power as the "ultimate" source of energy. In Canada, the question has not been seriously considered by the industry's energy association, but in private studies, preliminary thinking limits the potential role of nuclear energy in steelmaking to the use of one of the CANDU variants as a source of electricity for heating purposes, with off-peak power surplus applied to water electrolysis for hydrogen and oxygen production. In Europe, Japan and the U.S., options include using high temperature gas reactors (H.T.G.R.) as direct sources of heat for a number of purposes. If the technological difficulties associated with H.T.G.R. can be overcome, this system may prove advantageous.

In Europe and Japan particularly, the urge to reduce the dependence on fossil fuels is greater than in Canada. Although some Canadian steel companies may be members of international nuclear steelmaking "clubs", we must expect these other nations to lead the way in developing the new steelmaking technology. In consequence, although Canada may be spared some costly misadventures in technology development, the end result may well be another important industrial area where we must buy equipment from overseas when we are eventually ready to use the technology.

But whatever the outcome of this dilemma, we may expect that the industry's efforts to conserve fuel will have the effect of drawing together the sequence of processes which go into making steel. In a sense, of course, this has already been going on for a number of years. Changes in practices have occurred which have improved "thermal continuity" even if they have done less to promote the geographical propinquity of some operations. Indeed, to cite an extreme example, hot ingots have been transported many hundreds of miles between separate plants in railway cars filled with expanded mica.

Continuous casting (of billets) is another development which reduces the energy losses associated with traditional steelmaking practice and, at the same time, does much to confer continuity on the process of making steel. Canada is as much to the fore in developing continuous casting as any other nation and, currently, about 20% of all steel produced in this country is continuously cast.

The second major development which will contribute significantly towards continuity in steelmaking is the increasing use of pre-reduced sponge iron in the form of pellets, as a steelmaking furnace feed. One estimate suggests that the world production of iron pellets will grow from about 1.5% of pig iron production in 1975 to about 7% in 1985. Expansion in sponge iron pellet consumption is expected to be particularly rapid in favourable regions and, because of its economic structure, Western Canada could be one of these region.

The restricted size of the market for steel products in Western Canada has led to a steel industry of modest proportions based on electric furnace smelting. The reason for this is that steel can be made economically on a smaller scale in electric furnaces than when it is refined in oxidizing furnaces of the open-hearth of basic oxygen type. When steel is made in oxidizing furnaces most of the furnace charge comes from the blast furnace in the form of molten iron. A blast furnace will be necessary therefore in the steelmaking complex and, hence, production will have to exceed roughly 1 million tons per annum to be commercially viable. When steel is produced in an electric furnace it must be refined from a 100% solid charge. Thus, electric furnace practice is heavily dependent on scrap.

But just as the market for new steel is limited in the west, so is steel scrap scarce too, to the point that in times of a general scrap shortage, it cannot be "imported" even at ruinous prices. Thus, future plans for the expansion of steel in the west must be based on some other source of solid "iron units" than scrap, and accordingly, a future for pre-reduced sponge iron pellets in this region appears attractive.

Iron pellets for direct reduction call for special high-grade concentrates, low in silicon, but they lead to a product of uniformly high-quality, low in the trace elements which increasingly are being recycled in much of the scrap steel. Suitable concentrates should be forthcoming from mines in Northwestern Ontario, but at present, the only proven technology for producing pellets on an industrial scale depends on natural gas. Work is currently in hand to develop alternative processes using low rank coals, either directly as reductants or following gasification. At its current stage of development, the pre-reduced pellets-electric smelting path to making steel is not as thermally efficient as the blast furnace-oxidizing steelmaking furnace route. But the pelletizing process itself, the high-quality uniform feed-

stock it produces and electric furnace smelting, lend themselves as process elements to integration in an automated, energy conserving circuit, with a high degree of thermal and operational continuity.

3.3 Sulphide Minerals

Sulphide ores are important to Canada. Indeed, of the mines currently operating in the country, about 50% produce non-ferrous sulphide ores of one kind or another. The mineral complexity of these ores varies from the single species low-grade porphyry coppers to the multi-component, fine-grained ores of copper-zinc, zinc-lead, copper-zinc-lead and nickel-copper. In addition significant quantities of iron are present either in complexes with the marketable metal values or in discrete form as the sulphides, pyrite or pyrrhotite.

3.3.1 Beneficiation

Beneficiation is the first step to recovering the contained metals. Its purpose is to produce a "concentrate" for the extraction processes by reducing the gangue and other unmarketable material to the extent possible. Typically, it consists of two separate operations: first, comminution which embraces rock crushing and grinding, and second, a concentrating process which, with base metal sulphides, usually takes the form of flotation.

Beneficiation is important. The better the grade* of concentrate delivered to the smelter, the more efficiently and profitably can the metal be extracted. But high grade concentrates usually involve trade-offs with the amount of useable minerals dumped with the waste. In non-complex ores, the problem is not particularly serious. Acceptable concentrates can be produced with recoveries in excess of 90%. But with the multi-component fine-grained

*Per cent of desired mineral(s) in the concentrate.

ores, the difficulties of segregating several desirable minerals from each other, as well as separating them from the waste, are such that, to produce concentrates leading to profitable smelting, overall recoveries can be less than 70%. These losses are comparable with those encountered mining the ore.

Continuing research and development has led to great strides in methods and equipment but, in the light of the trend towards leaner and more complex ores, work must continue apace. All sectors can contribute - industry, government and universities. Industry will give priority to measures which improve efficiency and maintain competitiveness. Government, as guardian and expositor of the "national interest", will want to see new methods developed which will maximize the benefits to Canadians from the nation's mineral heritage. The universities can lend support to both sectors with selected fundamental and applied studies.

In the past, the approach to reducing costs in comminution has been to build bigger and bigger machines. Industry can be relied on to continue this development but the future prospect calls for some new directions in R and D and the early definition of some specific projects if mining is to remain profitable. There are some promising new ideas such as supermagnetism or selective flocculation which may provide the basis for new beneficiation processes, but it will be many years before they can be tested in industry. Meanwhile we should continue to try to improve existing processes. In flotation for instance, there is still scope for more selective reagents which, with the problems of water management in mind, should be bio-degradable. Computer based monitoring and regulation of complex flotation circuits used for processing multi-component ores is in its infancy and is, therefore, amenable to a great deal of development work.

3.3.2 Extraction and Refining of Sulphides

But beneficiation, of course, is only a first step to winning a metal from its ore. The processes which succeed it depend on a number of things including the metal being produced. As Canada's mineral production grows and efforts to expand domestic processing capacity begin to pay off, the need to build new plants will provide opportunities to introduce new metal extraction processes. A number of factors combine to stimulate change. Of these, the emerging environmental regulations are probably the most influential. But there are many others. Fuel requirements, for instance, are now of particular importance.

Although final decisions in industry about new process design will be in terms of economics, a number of engineering considerations will be reflected in the cost estimates. Productivity, operational flexibility, minimum viable unit size, the characteristics of the concentrate or feed-stock, and the market value of any by-products are some of the more obvious elements to be taken into account.

On the other hand, in Government, an interest in new methods springs from a concern for the low mineral recoveries which occur with the processing of some complex ores.

Work on process development is in hand. In fact, it has been and continues to be very active. As a result, a number of new methods and techniques now exist which represent a marked improvement on earlier practices. But with the variety in the many factors which determine the form of extraction process, there is still plenty of scope for progress in a number of areas. However, whatever the final form of a process circuit, ideally, it should convert sulphides to elemental sulphur, recover or reject the iron as oxide,

and separate the non-ferrous values from the waste. In all cases, there are probably no technological barriers to doing this, but in a free market economy, process costs must be recovered and the metal and mineral values marketed at a profit. It is this condition which places a limit on what is possible and may force trade-offs against the amount of minerals recovered, environmental impact, etc. It also places a high premium on scientific and engineering ingenuity.

A process circuit is devised from a number of potential methods to yield optimum results. There are many techniques available for the process metallurgist to choose from but they all fall into two broad classes - hydrometallurgy and pyrometallurgy. Either process can be used in both extraction or refining - the two distinct stages usually necessary to produce a metal of acceptable purity.

3.3.3 Hydrometallurgy of Sulphides

In hydrometallurgical processes, minerals or impure metals are digested in solutions of acids or bases and the product metals recovered in one of several ways. The process may be carried out at normal temperature and pressure or to improve reaction rates and secure good recoveries, it may be necessary to perform some processes in autoclaves at elevated temperatures and pressures. Even so, precious metals do not dissolve readily and chalcopyrite, the sulphide mineral form in which most of Canada's copper deposits are found, remains resistant to solution as well.

Of the several methods of recovering the marketable metal values from a leach or solution, electrolysis is the most commonly used. However, the thermodynamic efficiency of electrolytic processes generally is low and as a

result, the energy expended in producing a metal by electrowinning is likely to be greater than the energy consumed in a pyrometallurgical process, especially in one of the newer generation of pyrometallurgical processes using oxygen enrichment. Preliminary estimates suggest that the difference may be as large as a factor of two. However, in the long term, the cost and availability of energy in the form of electricity generated by nuclear reactors appears more certain than the future of fossil fuels, particularly, of course, oil and natural gas.

Hydrometallurgical processes have a unit size flexibility that is suited to Canada's circumstances. Large scale is not a prerequisite for economic viability and growth in plant production capacity can be matched to quite modest increments in market demand. Hydrometallurgical processes have been seized upon by some as the ultimate answer to the sulphur dioxide problem posed by conventional pryometallurgical operations. But hydrometallurgical processes can have environmental impacts of their own - acid disposal, for example, can lead to difficulties - and therefore the processes must be designed carefully.

Even so, as domestic ores become increasingly lean and their mineralogy more complex, the economics of mineral recovery may shift inexorably in favour of leaching as a means of extracting the marketable metal values from the ore. The limits to hydrometallurgy are still being assessed, but it is the object of continuing research to find ways around them.

3.3.4 Pyrometallurgy of Sulphides

On the other hand, pyrometallurgy will probably continue to be used for a long time to come. Indeed in the past five years, process engineers in the Canadian mineral industry have been active in developing what amounts to a new generation of extraction and refining pyrometallurgical processes. The

collective expertise gained through this experience should place the industry in a strong position to deal with present and future problems.

The oxidation reactions which take place during processing are exothermic*. As a result, some processes are virtually autogenous** and, in terms of energy consumption, very economic, even when the production of oxygen is taken into account. Reaction rates are high and so, therefore, is productivity. Furthermore, metal recoveries are good - for example, being about 98% in the case of copper.

Of the new equipment developed, the smelting furnaces are designed to minimize heat losses, promote efficient oxidation and curtail air ingress. Some of these furnaces employ oxygen enrichment. The result is that the volume of waste gas is reduced and the concentration of sulphur dioxide increased. This should materially assist sulphur dioxide recovery and control.

However, most non-ferrous metal sulphide concentrates are still smelted in furnaces which do not operate as efficiently as the newer ones and in consequence, produce large volumes of waste gas. These waste gases contain sulphur dioxide in concentrations which can be as low as about 0.5% for some reverberatory furnaces.

Sulphur dioxide is noxious and its emission from smelters should be controlled. At present, probably the most effective way of doing this is to make sulphuric acid. Gas streams containing between 4 and 10% SO_2 can be processed through double catalysis equipment with recovery efficiencies as high as 97 to

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*Give off heat

**Require no external source of heat to maintain temperature

98%*. Below about 4% SO_2, there is no completely satisfactory technology for handling waste gases in the quantities produced in a smelter and, apart from the precipitation of particulates, waste gases containing less than about 4% SO_2 are discharged to atmosphere. Hence, an economic method for concentrating dilute sulphur dioxide is worth continued effort to develop.

In any appreciable quantities, sulphuric acid is difficult to store. The demand for it is not reliable and is localized by freight rates which reflect the fact that for every ton of sulphur shipped, more than two tons of water have also been paid for. On the other hand, the long-term prospects for elemental sulphur appear reassuring. It can be stored cheaply and almost indefinitely. Thus, processes leading to the recovery of elemental sulphur, preferably as a by-product to the extraction of the metal, are desirable R and D objectives.

3.4 Aluminum

Aluminum is the most abundant metallic element in the earth's crust. In its pure form or as an alloy, aluminum has a combination of many useful engineering, electrical and chemical properties that are responsible for its application to a wide variety of uses; much so in fact, that in recent years, the proportional rate of growth in world consumption of aluminum has been about 40% greater than that of steel, the metal upon which modern civilization is founded.

Although aluminum is found in many minerals, its commercial exploitation is currently limited to the mining and processing of bauxite. Classically, aluminum is produced from bauxite in two distinct steps. First, a purified alumina (aluminum oxide) is extracted from the bauxite by some variant of the Bayer process. This step involves about 20% of the total cost of producing aluminum. The alumina is then reduced electrolytically in the Hall-Heroult process to aluminum.

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*without tail-gas scrubbing

The majority of the world's reserves of bauxite are found in the less industrialized countries; three countries in particular - Jamaica, Surinam and Guyana account for 40% of the world production. Canada, on the other hand, has no viable commercial deposits of bauxite and is, therefore, entirely dependent on imports of raw materials to feed its more than half billion dollar per annum aluminum smelting industry.

Known high grade bauxite deposits contain about 50% alumina* and on the basis of a 7% annual growth in world demand are estimated to have a life of about 50 years. Much more extensive lower grade bauxite deposits containing around 40% alumina also exist. As new deposits are developed it is probable that the alumina will be extracted in the bauxite-producing countries so that Canadian imports of bauxite as distinct from alumina, which in 1972 accounted for about 1.28 million tons (aluminum oxide equivalent) out of a total of 2.02 million tons, will decrease proportionately.

Canada is the world's fourth largest producer of primary aluminum, having built up a prosperous export business on the basis of an abundance of cheap hydroelectric power. Indeed 10% of all power generated and consumed in the country is used by aluminum smelters. The exclusive economic advantages which cheap power once gave us is eroding. The prime sites for power generation, readily accessible to ice-free ports, have already been developed. On the other hand, other countries are developing their power resources including such bauxite producers as Australia, New Zealand and Brazil. Thus, although domestic production of primary aluminum is expected to double by the end of the century to rather more than 2 million tons per year, there is a possibility that difficulties will be experienced in obtaining an adequate supply of alumina from traditional sources.

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*commercial grade aluminum oxide

In the spring of 1974, the major bauxite producers formed the International Bauxite Association and increases in the price of bauxite and alumina followed shortly thereafter. It is possible that the price of these commodities prior to the increases had represented something less than a "fair return" to the producing countries. But whatever the merit of the increases, the action revealed the vulnerability of Canada's dependence on overseas sources of supply for these critical raw materials, and, at the same time, raised questions concerning ability to process domestic resources of aluminous minerals should it ever prove necessary or desirable.

Although Canada does not possess any bauxite, it does have enormous surface deposits of anorthosite and, potentially large amounts of clays, shales and fly-ash containing about 20 to 26% alumina. Several processes have been worked out for recovering alumina from these materials. The lime-soda-sinter process, for example, produces a by-product useful for the manufacture of portland cement as well as alumina - in a ratio of 9 tons of by-product to every ton of alumina - and is in operation industrially in the Soviet Union. Elsewhere, work is underway in pilot plant facilities in the United States to recover alumina from a variety of aluminous bearing clays, shales, fly-ash and other materials; the opportunity for Canadian participation should be taken advantage of.

Direct reduction processes offer opportunities for enlarging the resource base of aluminous raw materials by eliminating the cost of producing alumina. In the light of the changing supply situation, some earlier studies probably warrant review.

Research and development in the technology of aluminum production is also active. In Canada, the rights to some technology from the Soviet Union aimed at improving the efficiency of the Hall-Heroult process have been purchased. In the United States, a new process has been developed to the pilot plant stage for reducing

aluminum from aluminum chloride. The process is reported to use about 30% less power than the Hall-Heroult process and, because it does not require fluorspar for fluxing, problems arising from fluoride emissions are avoided.

Per ton of aluminum produced, the Hall-Heroult process also consumes between 1100 and 1600 lb of pitch and carbon in the form of electrodes. At current prices, this item not only represents about 7% of the cost but it may be in short supply in the future. With this in mind, other studies are underway in the United States and in Switzerland with a view to electro-depositing aluminum from aluminum chloride using non-consumable electrodes.

Among other work on aluminum smelting processes, considerable publicity has been given recently to the new Toth process, but it is as yet scarcely tried beyond the laboratory stage.

3.5 Precious Metals

3.5.1 Silver

Canada is the world's largest producer of silver. Domestic output in 1973 amounted to almost 49 million troy ounces, 95% of which was produced as a by-product to base-metal processing. The production of silver, therefore, is essentially linked to base-metal production and does not of itself give rise to any particular technological problems.

3.5.2 Gold

While Canada is the third ranking producer of gold in the world, production only amounts to about 5% of the world total. Nevertheless, in 1973, Canada's output is estimated to have been rather more than 1.9 million troy ounces, worth about $186 million at the prices then in force. About 30% of this output is recovered as a by-product from sulphide mineral (base metal) processing and as such, does not create any particular technological problems. Almost all of the balance of production comes from lode deposits which sometimes contain silver values as well.

The gold occurs in concentrations of fractions of an ounce per ton of ore and frequently is extracted by leaching. Cyanide solutions are used for this purpose and, notwithstanding the dilute concentration of the gold in the ore, recovery efficiencies as high as 95% are common. To date nothing has been found to challenge the effectiveness of this process.

However, new and more stringent environmental regulations have focused attention on the need to develop the best possible water management practices to control plant effluents. Waste waters from cyanidation prosesses contain a number of different toxic compounds, some of which are more stable than others and resist natural decomposition in a tailings pond. There are known methods of dealing with cyanide wastes and it is the purpose of current research to evaluate these methods for their cost effectiveness.

To complicate matters, arsenic exists in several important lode deposits. Its presence adds to the difficulties of waste water management and calls for a pyrometallurgical pre-treatment to leaching. This, in turn, poses problems in atmospheric pollution which call for remedial action.

3.5.3 Platinum Metals

In 1973, Canadian production of the platinum group metals amounted to 288,000 troy ounces valued at about $37 million. This output originated almost entirely from the operations of two companies both of whom sent their platinoid-bearing residues abroad for extraction and refining.

3.6 Industrial Minerals

Industrial minerals and rocks* are utilized essentially in their natural state for their inherent chemical and physical properties. Many industrial minerals such as silica, stone, potash, phosphate, salt, etc., can be used directly with little or no processing beyond some sizing or simple beneficiation. Others, such as asbestos or phosphate, require more extensive processing or manufacturing to render them useful.

*exclusive of metal-bearing minerals and fuels

Economically, industrial minerals are important to Canada, their combined production amounting to about $1.28 billion in 1973 - a figure which represented about 25% of the dollar value of all non-energy minerals produced domestically.

3.6.1 Aggregate

As a building material, aggregate is by far the most important and, while it remains comparatively cheap, will continue to be used in large quantities. Compared with deposits of metallic minerals, deposits of aggregates occur widely. Transportation charges play a decisive role in the cost of delivered aggregate, tending to localize markets and open up opportunities for locally produced substitutes. At present, aggregate most often takes the form of sand and gravel, Canadian shipments of which amounted to $188 million in 1973. However, a continued expansion in demand for these materials is expected to generate serious shortages in the vicinity of large urban centres in the near future. This prospect indicates the need for compiling an inventory of aggregate resources in regions close to large population centres. In some areas, legislation may be desirable to prevent building on the site of gravel deposits. Nevertheless, despite these measures, supply problems will occur in some places which no amount of conservation or geological mapping can arrest. Thus, studies are urgently required with a view to converting such alternate low cost materials as shale, mine tailings, smelter slags, etc., into acceptable aggregate materials.

3.6.2 Cement and Concrete

Strictly specking, cement does not conform with the accepted definition of an industrial mineral and for this reason is often classified as a construction material. But its consumption is so frequently bound up with that of industrial minerals that it is appropriate to consider cement and concrete at the same time.

In a wide variety of pre-cast shapes and as ready-mix for on-site construction, concrete in Canada is big business. Some idea of its size can be gained from the value of cement production, which alone in 1973, amounted to about $230 million dollars. Approximately 95% of this was consumed domestically.

Despite some vertical integration by cement companies, the concrete industry is largely fragmented and very competitive - competing internally as well as with other forms of construction. In part, this may account for the fact that the industry's expenditures on R and D are very small. Indeed, total research funding from all sources represents less than one half of one per cent of the value of concrete production.

Fragmentation in the industry has led to many associations of one kind or another limited to representing sectional interests. Thus, although the use of concrete is now widespread and the importance of concrete technology is great, no national body exists which among other things, can act as a focus for coordinating R and D programs to tackle "Canadian" problems. As a result, the industry in Canada is obliged to fall back on making use of research performed elsewhere, particularly from the United States. In consequence, a number of topics have probably not been given the R and D emphasis which best serves Canadian interests. One example is a significant possible saving in energy over present cement manufacturing technology.

A recent independent study has recommended the formation of an institute broadly representative of the industry across the nation and suggests that this be encouraged by the offer of federal "seed money". The report envisages several functions it might usefully perform, of which the management of research programs on behalf of the Canadian cement and concrete industry is one. However, to date, discussion with the industry aimed at implementing the recommendations have not proved fruitful.

3.6.3 Asbestos

In 1973, the production of asbestos amounted to almost $250 million. In terms of sales volume, this makes asbestos the most valuable industrial mineral produced in Canada and makes Canada the largest producer and exporter of the fibre in the world. However, although we remain the world's largest producer, our share of the market has slipped as other countries, notably the Soviet Union, have begun to produce fibre in significant quantities .. Canada's early pre-eminence as a producer led to the development of an indigenous capability for manufacturing asbestos processing machinery which today has blossomed into a thriving consulting and export business. Continued technological development will be necessary to maintain a competitive edge.

The immediate prospects for asbestos sales appear buoyant but, competition from the Soviet Union apart, the long-term is likely to be determined by a balance between two opposing trends. Sales of fibre to developing countries for manufacturing asbestos-cement products are expected to expand; asbestos-cement products being well suited to the interests and needs of these countries. On the other hand, in the Western world, the effect of asbestos on health has recently received advserse publicity and is becoming an issue of growing concern.

Asbestos has long been recognized as an industrial hazard. Air quality standards for monitoring the exposure of asbestos workers to fibre inhalation have existed for a number of years in the United States and Britain. In Canada, occupational health standards now being set by regulatory bodies are becoming increasingly more expensive to meet and in some cases have resulted in production cuts. The processing of asbestos by wet methods, instead of by the traditional dry approach, would reduce air-borne asbestos problems but requires research and development.

However, until recently, certain pathogenic effects arising from the inhalation of fibre by workers in the asbestos industry were considered to be the only hazard associated with exposure to the mineral. But research has indicated that oral ingestion of asbestos from surface water supplies, from beverages and from foods prepared with water is pervasive. Clinical research shows that very fine fibres can penetrate the intestine of rats and enter the blood stream. Statistical studies have linked non-occupational exposures to ingested asbestos with various types of carcinomas, particularly of the gastro-intestinal tract.

The best available filtration technology can reduce the concentration of detectable fibres in water supplies by 99.8%. But the fibre concentration in regions removed from asbestos producing or processing areas is typically upwards of 1 million per litre and no one knows yet whether a 99.8% reduction is good enough. Indirect evidence suggests "high" asbestos fibre concentrations may be a part of the natural background level in waters the world over. The fibre contents of ancient ice masses or of water entrapments in archeological speciments have not yet been determined and hence, we have no means of comparing the levels which existed in early history against the levels which exist today.

Many other important issues have yet to be resolved, including such fundamental matters as the development of satisfactory sampling and fibre counting techniques to be used as tools for research.

Elsewhere in the world, a great deal of effort is being put into the development of substitutes for asbestos. Asbestos is important economically to Canada and as a nation, we have a vested interest and a responsibility to press the clinical studies and public health surveys currently in hand as a matter of high priority.

3.6.4 Fertilizers

Chemical fertilizers are commonly used to promote plant growth by supplying the nutrients nitrogen, phosphorus and potash in which many soils throughout the world are deficient.

Since the Second World War, a number of factors have combined to make Canada today one of the world's leading producers and exporters of chemical fertilizers.

Domestically, three major developments account for the present strength of the industry. The first was the discovery around 1950 of the large natural gas reserves in Western Canada, used extensively for the production of nitrogen containing compounds. The second was the recovery of elemental sulphur from the natural gas on a scale commensurate with the production needs for the sulphuric acid necessary to acidulate phosphate rock. Finally, the third factor has been the start-up of a potash industry in Saskatchewan with permanent production beginning in 1962. However, it can only be conjectured what these developments might have amounted to, had a fertilizer industry based on a substantial domestic demand and with a record of industrial achievement extending back almost to Confederation, not already existed.

Today, the industry's capacity for producing nitrogen is four times greater than domestic needs, phosphoric acid capacity is about three times and potash production capacity more than four times larger than necessary to satisfy domestic consumption.

3.6.4.1 Potash

Indeed, in 1973, almost 4.5 million tons of potash were produced with a value of more than $150 million, making potash the nation's second-most valuable industrial mineral in dollar terms.

The nature of the global trends which have created the current world food shortage are fundamental and long-term. Thus, excepting serious economic dislocation, the world demand for fertilizers should remain strong. If exploration activities for potash in New Brunswick, for example, lead to the discovery of commercially viable deposits, it should be possible to develop these without unduly impinging on the industry in Saskatchewan. Success in locating new reserves would be beneficial to all Canadians, as well as a means of overcoming the substantial freight charges to the eastern seaboard on a valuable mineral commodity.

In Saskatchewan, although the potash deposits constitute the largest known reserves in the world, mining recoveries are no better than 30-50%. There are no easy solutions to this kind of dilemma and the approach of provincial authorities in setting up a program in rock mechanics in the provincial Department of Mineral Resources seems as good as any. In practical terms, this program is aimed at increasing mining recoveries and improving mine safety.

The potash is associated with halite (common salt) which occurs in quantities many times greater than there are markets for and thus, for the time being at least, the salt must be wasted. Brine is pumped into wells about one mile deep and, the slurry is discharged into dyked areas on surface at a total rate for all mines approaching 9000 acre-feet per year.

In the vicinity of some mines, there has been localized salt contamination and some complaints about corrosion but otherwise no serious problem has occurred to date. Nevertheless, various techniques including aerial surveys are used in a comprehensive monitoring program to ensure continued containment of the salt. To this end also, other provincial programs are directed towards embankment stability problems and a study of the long-term

effects of brine on the local clays. Meanwhile, however, the growing piles of salt do little to improve the local scenery, and eventually returning the salt to the mines would not improve chances of recovering the 50-70% of the potash left underground.

3.6.4.2 Phosphate

Canada's fertilizer industry began in 1869 when a chemical company was established in Brockville, Ontario to treat the phosphate rock (apatite) mined in nearby Lanark County. Apatite mining expanded rapidly throughout the Rideau Lakes area of eastern Ontario and spread into southwestern Quebec. But in 1881, rich sedimentary rock deposits were discovered in Florida which shortly thereafter entered the Canadian market. Domestic producers withstood the competition until the early 1890's when the industry collapsed.

Today, essentially all supplies of phosphate rock processed in Canada are obtained from the United States. In 1973, they amounted to about $24 million. Apatite still exists in Ontario and Quebec and there are sedimentary deposits over large areas in the Rocky Mountains of Alberta and British Columbia which are too low in grade to be mined economically in the face of the competition from off-shore supplies. On a world basis, supplies are expected to be adequate to meet growing world demands. But in Canada, there is increasing concern that environmental restrictions imposed on producers in the United States will prevent them from expanding output and thus being able to meet growing requirements. Consequently, we may have to diversify our sources.

However, if agricultural research can reduce the 3 to 1 ratio of phosphorus lost to the soil to that taken up by plants, the demand for phosphate supplies may ease. Nevertheless, it is desirable that Canada take steps to reduce its complete dependence on off-shore sources for supplies of this essential mineral.

In the circumstances therefore, federal-provincial initiatives are warranted to stimulate further exploration. At the same time however, although the quantities involved may not be large, opportunities to produce phosphate as a by-product from other mineral development activities warrant consideration. The occurrence of apatite with titaniferous magnetite in Ontario, the presence of substantial amounts of phosphorus in the Peace River iron deposits and the association of apatite with columbium bearing minerals in parts of Quebec are examples which spring readily to mind.

When the phosphate rock is digested in acid, large quantities of gypsum are created as a by-product. Indeed, for every ton of fertilizer equivalent, about 4.5 tons of waste gypsum (calcium sulphate) are generated. This residue is finely divided, acidic and contains fluorine. It is expensive to dispose of, but it has potential for the manufacture of wallboard and other plaster-based products which, if it is to be exploited commercially, must be appraised for economic feasibility on a case by case basis.

4.0 SCIENCE & TECHNOLOGY REQUIREMENTS FOR THE UTILIZATION OF MATERIALS

4.1 Introduction

For centuries man used his ingenuity to convert resources, more or less readily available from nature, into usable materials. Over the past few decades the knowledge base in the field of materials science and engineering has been greatly expanded, resulting in the development and utilization of a broad range of new and radically different materials. Society, with its increasingly complex technology, will continue to impose increasingly stringent demands on materials utilization. There will always be requirement for better or cheaper materials for old or new applications. Public concern over safety, the environment, and the availability of energy and mineral resources, will reinforce this continued search for safer, stronger, more durable and more reliable materials.

What then does the future hold in the field of "materials science and engineering"? What are the long term national objectives, and what technological advances will be required to meet these objectives? Past experience has taught that scientific progress can best be achieved through research and development programs conceived to resolve specific practical problems, but which are carefully balanced between the fundamental and the applied. Our basic understanding of most materials falls far short of the level required for many new applications. Although the urgency will vary for different applications, it is necessary to continue to add to the store of fundamental knowledge to ensure that a sound theoretical base is available to solve engineering problems as they arise. Since these practical problems must have relatively short term solutions, the lead time required for the initiation of fundamental studies could be in the range 5 to 15 years. It is important therefore that technological requirements be accurately forecast and basic research be carefully chosen to ensure that the data necessary for the optimum utilization of materials will be available with a minimum of development time and expenditure.

Although this discussion is theoretically confined to outlining the science and technology requirements for the utilization of mineral-derived materials from the non-energy segment of the mineral industry, it will become increasingly apparent throughout the text that the development of materials cannot be restricted by limitations on material sources, and that the utilization of materials cannot be confined to non-energy applications. All natural resources, including wood, water, natural fibres, rubber, grains, fossil fuels, etc., must be fully utilized if we are to develop the best materials possible for specific applications.

4.2 Fundamental Research on Materials

There is today a very large variety of materials with exceptionally diverse physical and chemical properties. As a consequence, the scope for fundamental research is almost limitless, and priorities are difficult to define. To stay abreast of advancing technology, Canada with its limited financial and technical resources, must encourage participation in co-operative research programs with other developed nations. Also, Canada must through reciprocal agreements which provide for exchange of information, maintain the knowledge base necessary to ensure continued progress in materials utilization.

Scientists have made remarkable progress in understanding the properties of single-crystal materials, particularly the electrical and optical properties of semiconductors. This theoretical background in solid state physics has in many cases made if possible to select in advance specific materials possessing desired properties. Similar progress however, has not been made in relating the properties of individual atoms to those of imperfect solid materials made up of such atoms. Since most materials are in this category, it is highly desirable that a broader knowledge base be obtained in such areas as interatomic forces, chemical bonding, lattice stability and phase transformation, as they relate to the bulk properties of polycrystalline, amorphous or polymeric forms of matter. The amorphous or disordered state offers a particular challenge for scientists to relate mechanical, chemical, electrical and optical properties to outside factors such as light, heat, stress, radiation and the presence of impurities. Polymeric materials, both natural and synthetic, also remain a prime challenge for fundamental research, and the field of organometallic complexes and composites has barely been touched. A better understanding of these fundamental concepts is a prerequisite for solving practical materials problems such as

those relating to structural strength, stress corrosion cracking, superconductivity, magnetic and dielectric susceptibility, light and sound attenuation, and radiation damage.

Another area where fundamental research can be most fruitful involves surface and interface phenomena. Basic knowledge of the physical and chemical properties of surfaces can be significant in assessing the performance of materials in many applications. The mechanisms controlling the electronic and anisotropic properties of thin films; the effectiveness of protective coatings and inhibitors for corrosion protection; the corrosion, erosion and lubrication interaction during frictional wear; adhesion; adsorption; catalysis; flammability and crystal growth -- to mention just a few topics -- are affected by, or dependent on surface properties. Our understanding of surface phenomena is in general inferior to out understanding of bulk properties, and with the complexities of each being about equal, it is essential that the effort expended on fundamental studies of surfaces be at least equivalent to that on bulk properties.

Another area of fundamental research which cannot be neglected is that required to develop sophisticated methods and equipment to accurately measure the wide range of physical and chemical properties encountered in present day materials. Although we have many modern tools at our disposal, still more are required if we are to obtain a better understanding of fundamental properties, and ultimately better control over the preparation, characterization and utilization of materials.

4.3 Applied Research on Materials

4.3.1 Resource Industries Applications (excluding oil, gas and coal)

Continued depletion of high grade, easily accessible mineral resources will lead inexorably to a need for new mining methods and materials to effect economical recovery from leaner and less accessible ore bodies. There will be

a demand for harder and stronger materials, possibly composites or ceramics, which are more resistant to wear and corrosion for specific applications such as hard-rock mining and drilling equipment; for open-pit excavating equipment (particularly for the oil-sands); for ore grinding and for solids or slurry transportation. New mining methods, such as automated continuous mining, hydraulic mining, "robotics" or in-situ extraction will be required where economics dictate, or where working conditions are intolerable to man. These will impose new equipment design and materials requirements, dependent on the particular environmental conditions, with the oil-sands being an uniquely Canadian problem.

4.3.2 Transportation Applications

Transportation systems consume enormous quantities of materials. The increasing emphasis on energy conservation wil exert new pressures to develop transportation modes consuming less energy. This will undoubtedly lead to a demand for lighter-weight longer-lasting vehicles, with greater efficiencies of energy utilization, and a trend toward electrical methods of propulsion for land transport systems, particularly for mass transit. Of equal importance is the development of superior lubricants and lubricating systems to ensure minimum frictional wear in bearings or other moving parts, and also to obtain maximum energy utilization.

4.3.2.1 Land Transport

The automobile is and probably will continue to be the major vehicle for passenger transportation, particularly for short distances. It will become increasingly necessary to up-grade safety standards and reduce environmentally undesirable emissions without increasing weight, cost or energy consumption of the vehicle. This will require the development of cheaper, more efficient

emission control systems and high strength light weight construction materials such as HSLA steels, or alloys of magnesium or aluminum. To increase vehicle life will require better materials or methods of protection from salt corrosion and hot exhaust gases. New fuels such as hydrogen or methane, or new methods of propulsion such as electrochemical cells, probably with solid-state electrolytes, could of course impose new and entirely different materials requirements, with safety considerations having a very high priority.

Electric propulsion units for mass transit will require more efficient energy conversion and transfer systems to ensure optimum use of the energy source. Safety regulations will again impose stringent specifications on the flammability and electrical properties of materials for use in these systems.

Railroads are and will continue to be the main method for the bulk transport of goods and raw materials across Canada. Even now however, rail capacity is insufficient to cope with the demand, and double tracking, especially in critical areas such as the Rockies, is essential to meet future requirements. Excessive rail wear on curves due to larger and heavier cars has also significantly reduced track capacity and increased maintenance costs. It is desirable therefore, to develop rail steels which are stronger and more resistant to wear under the conditions to which they are presently subjected. Car wheels should be improved by developing steels more resistnat to thermal stresses introduced by braking, which at present can be a cause of failure sometimes with catastrophic results.

4.3.2.2 Marine Transport

Canada's main areas of interest in marine transport will probably continue to be associated with inland waterways, (the Great Lakes and St. Lawrence Seaway) and to an increasing extent the Arctic, where Canadian-developed technology can be uniquely applied, and where Canadian-built ships are likely to be

more competitive. There will be a demand for stronger and more corrosion resistant steels for ice-breakers, not only to facilitate Arctic navigation, but also for increasing the length of the shipping season in inland waters. More powerful and energy efficient propulsion systems will also require materials with superior strength and erosion-corrosion resistance for steam or gas turbines, ships propellors and possibly hydrofoils. Nuclear propulsion systems and tankers or combination tanker-ice-breakers, particularly for the transportation of oil or gas from the Arctic, will create a further demand for superior, reliable materials of construction to ensure the safety and environmental integrity of this transportation mode.

4.3.2.3 Air Transport

Although air transport systems are inherently more energy intensive than most other transportation modes, improvements can be effected through science and technology designed to increase the lift to horsepower ratio, or the thrust to weight ratio. Either method is likely to create a demand for stronger but lighter materials of construction. Also required are superior materials for turbines to withstand temperatures in excess of 1000°C. These materials must be strong and dimensionally stable and must have excellent oxidation resistance. Their manufacture will undoubtedly require the advanced technology associated with the development and fabrication of metal-ceramic composites, structural ceramics, or refractory metals.

4.3.3 Communications Applications

Existing communications network relies heavily on the use of wire and cable, electromechanical equipment and microwave transmission. Continued progress can be expected in these areas through the use of solid state electronics, circuit miniaturization and better, more reliable hardware. However,

the growing congestion in telecommunications systems, caused by their increased use for data as well as video and audio transmission, will necessitate the development of higher capacity systems for both long and short distance communication.

Here optical transmission methods will command a very high priority. Light theoretically offers the fastest potential means of communication. The development of the laser has provided a prime method for utilizing this potential. For effective transmission however, the light beams must be "piped" in optical wave-guides which will transmit the signals with minimum loss regardless of the circuit path. Precision manufactured high purity ductile glass fibres have been developed which appear certain to make the use of light for telecommunications a reality in the very near future. A single optical wave-guide using high frequency optical wave length transmission could replace 10,000 ordinary telephone wires. However, many problem areas still remain, such as methods of modulating and demodulating from a laser source, terminal devices, optical couplings and the usual problem of developing the most economic process for the manufacture of these extremely fine glass fibre optical wave-guides. A concerted R and D effort will be required to resolve these problems.

4.3.4 Construction Applications

The construction industry in general offers a wide scope for the development of better materials for specific applications. To conserve materials and reduce costs there will be a continuing demand for higher strength to weight ratio materials of construction. Of primary interest here are HSLA steels and reinforced concrete, both of which will command a high priority for research and development dollars. In concrete, the replacement of stone with light-

weight aggregate, possibly derived from mineral wastes, and the use of metal or glass fibre re-inforcing in place of steel rods, are two areas where research could pay handsome dividends in the form of a lower density product, with improved tensile and flexural strength.

There is also a need to improve the properties of concrete in other areas, such as resistance to thermal stress (freezing and thawing) - particularly for Arctic applications, and resistance to wear and corrosion, especially chemical attack. Resolution of these problems will result in increased use of concrete in preference to less abundant resource minerals, such as petroleum derivaties for roads and other construction applications.

With the continued emphasis on energy conservation there will be an increasing incentive to produce better materials for thermal insulation, both for housing and high temperature equipment. These materials will preferably combine strength, fire retardation and thermal insulating properties, with low cost and easy installation.

Increasing dependence on northern resources will create a demand for metallic materials having superior low temperature strength and toughness for many structural applications in the Arctic, by far the most predominant of which will be gas and oil pipelines. Here HSLA steels will be in great demand. Requirements for pipelines are adequately covered in another document on energy policy and therefore need not be dealt with here. In addition, there is a need for comprehensive studies on a variey of other materials, such as stainless and other alloy steels, and nonferrous alloys of magnesium, aluminum, and possibly titanium to obtain performance data at low temperatures, and to identify those materials which are most suitable for such applications as power transmission towers, drilling rigs, off-shore installations, bridges and microwave towers.

There is also a continuing requirement for structural materials which have superior strength and corrosion resistance for the chemical and metallurgical processing industries, in particular for applications involving halides or sulphides or reducing atmospheres at high temperatures and pressures. Typical examples are hydrometallurgical and heavy water processes, coal gasification, and thermal hydro-cracking of bitumen. Problems such as stress corrosion cracking, hydrogen embrittlement and lamellar tearing are major sources of concern requiring considerable investigation into the combined effect of stress, metal quality, structure geometry and the environment.

4.3.5 Energy Applications

Although material requirements for energy applications are covered in a separate "Energy Policy" document, we would be remiss in not mentioning briefly the major areas where science and technology are required for the development of these materials.

The problem of power loss in electrical transmission will create a continuing demand for better insulating and conducting materials, with superconductors being of special interest.

Alternate energy sources will also impose exceptional demands on materials for solar energy conversion, magnetohydrodynamic generators, fuel-cells and thermonuclear fusion processes.

The incentive to operate at higher temperatures to improve conventional thermal to electrical conversion efficiency will create further demands for materials with superior high temperature strength and corrosion-erosion resistance for high temperature gas turbines, for boiler tubes and for Candu nuclear power reactors.

The development of adequate energy storage systems will also require materials development to ensure efficient, reliable, easily convertible methods for energy storage.

There are many material requirements related to gas and oil transportation, and coal and oil sands utilization, most of which have already been mentioned under construction and mineral resource applications.

4.3.6 Materials Conservation

The increasing world demand for materials has resulted in resources being extracted, processed and consumed as products at ever increasing rates. In addition, waste products, generated from mining and processing of these resources and from discarding of the products after their useful life has ended, have created serious environmental problems. It has become increasingly clear from both an environmental quality and resource conservation point of view, that this open-ended materials cycle is no longer acceptable, and must be replaced with a closed cycle incorporating recovery, reprocess and reuse of materials. The recycling of metals can also result in a considerable reduction in energy requirements, since the energy expended to extract metals from their ores does not have to be expended again. This energy saving can range from 80% for iron to about 98% for magnesium.

Planning conservation policy must take into account the three ways whereby more effective use of mineral and metal resources can be achieved; substitution, recycling and utilization of by-product wastes. Canada is considered to have abundant resources of several important metals including iron, copper, nickel, and lead. For these metals conservation practices probably should be directed towards the development of improved recycling techniques. In other instances where our raw material resources are limited, attention should be turned to finding suitable substitutes for some uses, thus conserving the resource in question for top priority applications. Substitution is of particular importance where the use pattern is such that recycling is impossible or difficult. This is

known as a dissipative use and examples are the use of zinc in paint and galvanizing, and silver in photographic application.

Finally, there is the concept of conservation through the utilization of by-product wastes, especially those which create environmental problems, and for which there are no economic uses. Ideally, these waste products would be utilized as substitutes for, or as supplements to materials derived from more costly or less plentiful resource bases, thus contributing to the conservation of these resources.

4.3.7 Substitution

Substitution is usually done because of economic considerations. One material is substituted for another because the combination of cost and useful life is better. However, substitution for the purpose of conservation, or to contribute to national self-sufficiency, does not necessarily offer any economic advantage and may even incur an economic penalty. Manganese and chromium are two commodities which are important for steelmaking, but are deficient in the Canadian mineral resource base. Their substitution in steel with more domestically abundant materials, such as vanadium or molybdenum could be considered. On the other hand complex low grade deposits of manganese and chromium are available in Canada, and it may be more expedient to develop processes for their efficient recovery and use, than to attempt to develop a market and obtain acceptance for a new product, which may have equivalent properties, but which does not conform with normally accepted specifications. Compared with imported manganese and chromium ores, neither approach is likely to have any immediate economic benefits. Nevertheless, to guard against possible external price or supply manipulations of these ores, projects to evaluate processes for utilizing domestic sources, and to determine the extent to which substitution of these elements in steel is possible appear worthwhile. However,

the effect of substitutes on steel properties must also be carefully and thoroughly evaluated, and the steel on which the experiments are carried out must be carefully chosen with all relevant factors in mind.

Aluminum is another metal which has attractive physical, electrical and chemical properties and which is used extensively in Canada, although produced exclusivey from imported ores. Although Canada has no deposits of bauxite, we do possess very considerable deposits of lower grade aluminous bearing minerals, and aluminum, (along with silicon, magnesium and iron), is one of the most abundant elements found in the earth's crust. Substitution for less plentiful elements, such as copper or zinc, could therefore be justified. Also national self-sufficiency could be assured by developing efficient processes for recovering aluminum from domestic deposits. Aluminum has already replaced copper for most electrical transmission applications and its expanded use for electrical purposes should be encouraged. Aluminum however, does have inferior strength properties to copper, and more effort is required to improve these properties for electrical applications such as house wiring and motor windings.

Canada is dependent on many other minerals which are not domestically abundant and on which world shortages may develop within the next 35 years. Examples are those of tin, mercury, and zirconium. Some other minerals which are presently abundant but which could become in short supply due to projected rates of consumption and depleting ore reserves are those of zinc, copper, silver and fossil fuels. Although substitution by more abundant minerals may resolve the shortages in some cases, there is no general formula that can be applied and each case will have to be resolved on its own merits. Thus aluminum cans or plastic batteries could be substituted for lead-acid batteries. Aluminum or magnesium alloys may replace titanium for certain aeronautical applications,

or replace zinc for corrosion resistant die castings. There are however, no suitable substitutes for zirconium for Candu reactors, or silver for photography, and in these areas very efficient recovery and recycling methods must be developed if we are to avert a serious material shortage.

Dissipative uses of metals with limited supply bases, such as zinc for galvanizing, cadmium for electroplating, and lead or titanium based pigments for protection of structures, must also be minimized. Although this can be accomplished by substitution with more abundant mineral base resources, such as aluminum, enamels or ceramics, it can also be achieved by changing the base structural material so that it does not require protection.

Studies should be undertaken to identify and publicize the dissipative uses of metals as a preliminary measure. This is a matter in which Canada shares an interest with other nations. In co-operative programs of one kind or another, there will be opportunities to participate in this and related ventures in such international forums as the U. N., O.E.C.D., and N.A.T.O.

Also to be considered are substitute sources not presently being utilized for these potentially scarce materials. Thus, ilmenite or titaniferous magnetite, although more costly to process, will eventually replace rutile for the production of pigment grade titanium dioxide and titanium metal. Renewable resources such as wood, rubber, natural fibres, grains, and sugar, can be substituted for non-renewable fossil fuels, as sources of polymers, plastics, hydrocarbon chemicals, and ammonia. In fact substitution of the fossil fuel base is essential to the survival of those materials. Oceans and sea nodules must be considered as sources of many raw materials, (alkali and alkaline earth salts, chlorine, bromine, iodine, hydrogen, deuterium, uranium, and heavy metals) the eventual recovery and utilization of which will be dictated by economics or

the lack of an alternate resource base. These alternatives will have to be carefully evaluated to determine how a new resource base will affect the economics of a particular material, thereby establishing where substitution is most required, and what substitute materials will provide optimum product quality and maximum resource conservation.

Environmental problems associated with materials utilization can also contribute to replacing these materials with less toxic substitutes. Typical examples are mercury, asbestos, arsenic, cadmium and lead, all of which are potentially hazardous under certain conditions and without appropriate safety measures due to their toxic or carcinogenic properties. In some cases these problems may be resolved by substitution, or by changing the end use pattern to prevent dissipative uses thus eliminating the environmental hazard. A typical example of the latter is the removal of lead from gasoline. However, applying such drastic action to an industry as important to the Canadian economy as asbestos could result in a serious depression. It is expedient therefore to avert such possibilities by developing safeguards for utilizing these materials without creating environmental hazards and thus obviating the need for substitution.

4.3.8 Recycling and Waste Utilization

Regardless of improvements in processing and utilization designed to conserve materials and energy, efficient recycling of materials is essential for the long term conservation of the world's resources and for maintaining a "clean" environment. Recycling however, can never be completely one hundred per cent effective, not only because of the unavoidable dissipative uses of some materials, but also because no process, recycling or otherwise, can obtain perfect recovery of the desired products.

Fortunately, recycling has been practized by the metals industry throughout the world for a great many years. Indeed almost 30% of the iron and steel produced and over 50% of the copper produced originate from scrap sources. Although technology for recycling metallic scrap in the form of discarded automobiles and appliances, is further advanced than that for recycling municipal garbage or other predominantly non-metallic wastes, more efficient processes are still required. Ideally these processes will separate the ferrous and non-ferrous metals, and will facilitate either the separation and recovery of individual non-ferrous metals (aluminum, magnesium, copper, zinc, lead, etc.), or the production of non-ferrous alloys with desirable properties for specific applications. Also required are economic methods for the removal and recovery of trace quantities of non-ferrous impurities (copper, tin, zinc, cadmium, cobalt, lead, etc.) from the ferrous product. Some of these impurities (Zn, Cd, Pb) can be fairly readily removed as volatile oxides in the steel making process and require only adequate methods for their separation and recovery. Others such as copper, tin and cobalt are very difficult to remove and can be deleterious if allowed to build up in the steel or ferrous alloy products. Considerable effort will therefore be required to develop physical, chemical and metallurgical processes to efficiently and economically remove and recover usable non-ferrous products from predominantly ferrous scrap, while keeping losses in the process due to degradation and oxidation to a minimum.

The more complex materials become, the more difficult recycling will be. Recycle processes for composite materials containing both metallic and non-metallic components will undoubtedly require advanced technology to make recovery and reuse economic. Even today the variety of metal alloys utilized is substantial, and can be expected to increase. Direct recycling of these alloys will require either much better methods of identification and separation, or much

more sophisticated techniques for analysis and control during remelting. For composite materials the same problems exist, but remelting may not be possible if the desired properties can only be obtained by powder metallurgy or other specialized fabrication techniques.

Recycling choices will at times have to be made, and although economics will likely lead to recovery of the most desirable components it is important to ensure that the major emphasis is always on recycling of those materials which have the most deficient resource base.

One of the largest sources of predominantly non-metallic solid waste is municipal garbage. In Canada approximately 10 million tons are produced annually, most of which is disposed of as land fill. A typical composition of this waste material is as follows:

food and yard wastes	35%
paper	35%
other organics (plastics, rubber, wood, textiles, etc.)	10%
glass	10%
metals	10%

The efficient recycling and utilization of these wastes pose many problems, ranging from the methods used for collection, sorting and separation, to final processing which is dependent on the final method of utilization.

If the collection system is designed to collect clean newspaper or corrugated paper separately, then it is possible to recycle these materials to the paper making process. This however only amounts to about 5 to 10% of the total combustible products discarded, and the economics may be somewhat questionable. The remaining combustibles, which still amount to about 60 to 70% of the total municipal waste, can probably best be utilized as a source of energy, either by direct combustion in a utility boiler to produce steam for heating or power generation, or by pyrolysis to produce a synthetic gas or liquid fuel.

A number of pilot facilities have been built and operated in the United States to separate and recover glass, iron and aluminum from the non-combustibles, and synthetic gas, oil or direct heat from the combustibles. Based on the pilot plant results, a number of commercial plants are now under construction. In Canada, however, little has been done to date in building facilities to recover and utilize municipal wastes. Even assuming the availability of United States technology, much remains to be done to optimize the recycling process. Colour sorting of glass, separation of aluminum can tops and tin from steel cans, determination of optimum methods for utilizing the fuel from processing of the combustibles, and the recovery of noxious effluent gases (HCl, Cl_2) from the combustion of rubber and plastic materials, are all areas requiring considerable research and development.

Recycling problems can of course be tempered considerably without improving technology by introducing appropriate legislation to promote recycling and reuse. Standardization of bottle size and shape for consumer goods, a compulsory monetary refund and a ban on disposable bottles would greatly reduce glass recycling problems. Similar legislation on cars and appliances would prevent indiscriminate disposal and reduce collection costs for metals recycling.

It is apparent that technology alone will not ensure optimum recycling and reuse of all materials, and that to ensure maximum conservation of resources through recycling, some legislative support will be necessary.

The conversion of mineral and industrial wastes to useable products is probably the area of recycling in which we are most deficient in technology. Typical examples of waste products which could be effectively utilized are: pyrometallurgical slags from smelters or steel making, fly-ash or coal-ash from thermal plants, lignin from pulp and paper mills and tailings from mining and milling operations. The fact that many of these waste products are environmentally

objectionable provides further incentive for their economic utilization. Thus we can consider slags as aggregates for conrete, and fly-ash or coal-ash for brick making or for concrete additives.

Steel-making slags can also be considred as potential sources of manganese or phosphate if economic processes can be devised for their recovery.

Mine and mill tailings may be suitable for road construction or railroad ballast, or it may be possible to process them into mineral wool, gypsum or other construction materials for the building industry.

Organic wastes can often be utilized as fertilizers. But they can also be considered as a source of raw materials for the production of synthetic polymers (possibly biodegradable) or organic chemicals by fermentation processes. Lignin, too, is a waste product generated in large quantities, which offers attractive possibilities as a raw material base for the production of organic chemicals, bonding agents or ultimately synthetic polymers. However, technology in these areas is limited and much remains to be done if we hope to economically and effectively utilize these waste products to help conserve our natural resources.

5.0 SUMMARY

5.1 Introduction

This summary of the impact on mineral policy development of science and technology deficiencies in the mining, processing and utilization of minerals is organized to correspond to the various imperatives identified in the mineral policy review document "Towards a Mineral Policy for Canada - Opportunities for Choice". The order in which the S & T requirements are presented here does not reflect, in any way, priority judgements.

In the policy review document, a high priority is given to the increased diversification and growth of national and regional economies based on minerals. This cannot be achieved without giving due consideration to the technology needed to improve health and safety in the working place, and to protect the natural environment. Another high priority item is the assurance of an adequate supply of minerals for Canada's future needs. In meeting this objective, technological advances that will make it economically possible to mine and process lower-grade, more complex and deeper deposits with increased recovery, and recycle more of our waste will also lead to the extension of the viable life of mines and mining communities, the development of new mining districts, and the conservation of our resources.

From the foregoing, it is seen that technological advances rarely impact on a single organizational objective whether the organization be an industry, a government or a community. This is why the assigning of priorities to S & T activities, even when a clearly stated policy is enunciated, is difficult. Undoubtedly scientific and technological advances that respond to the major demands of the community at large will have the highest priorities. Currently these are the technological innovations needed to improve the levels of health and safety in the working place, reduce degradation of the natural environment, encourage further processing of mineral products prior to export, provide an assured supply of mineral products for future needs, and conserve mineral resources. Science and technology needs are listed in this summary under the issues on which they will have the greatest impact with references made to other applicable issues.

5.2 Employee Health and Safety and Protection of the Natural Environment

a) The protection of workers from inspiring dangerous levels of dust, with special emphasis on quartz, asbestos and radioactive material, is of immediate concern.

Research is needed to determine "safe" levels, to develop technology, either to reduce dust concentrations to acceptable levels or to isolate the worker from the dust condition, and to develop continuous monitoring systems. Dust in asbestos ore processing plants can be controlled by available dust-collecting technology at relatively high cost. Research on wet concentration of asbestos, a potentially cheaper approach, is worthy of study.

b) Diesel and explosive fumes and noise are three other sources of pollution in mining operations that need attention.

c) As mines are forced to go to depths of a mile or more in the search for new ore, methods must be found to lower the temperature and humidity in labour intensive working areas. The Sudbury nickel mines are examples. One solution to this problem, which would also contribute to lower costs, would be provided by developing an automated continuous mining system for hard rock, thus greatly reducing the need for manual labour underground. (See also section 5.6)

d) There are a number of areas where new technology is needed to improve the management of solid, liquid and gaseous wastes from mining, processing and utilization operations. Some of the more important are the weathering of sulphide-bearing tailings resulting in acidic run-off and seepage containing iron and other metals, the rehabilitation of waste impoundment areas through revegetation or other means, the rehabilitation of open-pit mining areas, the control of sulphur, arsenic and lead air pollutants, and the control of cyanide and arsenic-bearing waste waters. (See also sections 5.3 and 5.5)

.3 Further Processing of Mineral Products Prior to Export

a) Constraints to the development of increased plant capacity for processing sulphide concentrates to metal include the national concern that such a policy would greatly increase the pollution problems that have come to be associated with conventional smelters, and the fact that conventional smelting requires significant quantities of oil and gas as energy sources. Technology is consequently needed for processing that would eliminate or minimize the production of SO_2, reduce the overall waste management problems, and use coal or electricity coupled with more efficient energy use. (See also section 5.2, 5.4 and 5.5).

b) Employee health problems caused by asbestos dust is one of many constraints to increasing Canada's capacity to turn this mineral into higher-value products. The major constraint is related to foreign ownership, but new technology to reduce the health hazard is important. (See also section 5.2).

c) That sector of the Canadian economy concerned with converting metal and mineral products into semi-finished materials makes a major contribution to domestic mineral-based manufacturing. In this activity there is pleanty of scope for technological innovations, all of which would have significant impact on policy development. A few of the areas of interest are hot-rolling of high-strength, low-alloy steels, continuous casting, and the production of metal composite and ceramic materials for the electronic, nuclear, transportation, space and other high technology sectors.

5.4 Assuring an Adequate Supply of Minerals for Long-term Needs

Canada's mineral resources are large, diversified, and widely distributed. However, there are technological constraints to the conversion of a significant proportion of our resources to economically exploitable reserves. If we are to ensure a long term supply, not only of those minerals in which we have been traditionally self-sufficient, but also of those upon which we are dependent on foreign sources, new technology will have to be developed.

a) New mining methods are needed to operate economically at depths of over a mile and to solve problems related to rock support; worker health, safety and comfort; and materials handling. Specific requirements are for automatic mining equipment for hard rock mining, hydraulic hoisting technology, and methods of mining large openings at depths of over 4000 ft. Future production rates of nickel, copper, lead, zinc and gold could all be affected by lack of required deep-mining technology. (See also section 5.6).

b) In many underground operations, the amount of the resource that can be brought to surface is constrained by the need to leave a large percentage underground as support pillats. In uranium mines in Ontario up to one-third of the ore must be left as pillars while two-thirds are left in potash mines. Technology that will allow for recovery of most or all of the support pillars would increase our recoverable-resource inventory. (See also section 5.5).

c) Because of their complexity, recoveries of total metal values from many of Canada's zinc-copper and zinc-lead-copper sulphide ores are very low with efficiencies of only 70% or less. In fact, in some instances the

deposits are not being worked because of the lack of suitable technology. If the full potential of these deposits is to be realized new beneficiation and metal recovery technology must be developed. Such a development would also mean additional processing of minerals prior to export. (See also 5.3, and 5.5).

d) There are a number of nickel-copper deposits in Canada that are too small to support smelters and for one reason or another find custom smelting unattractive. Technology that would provide for a low cost, low capacity metal-producing facility would not only encourage the development of these smaller properties, but also promote additional regional development and further domestic processing.

e) Western iron ores and eastern titanium-bearing magnetites are not being mined because suitable technology for their treatment is unavailable. Although Canada's reserves of conventional iron ores are adequate for the remainder of the century, technology for these complex ores would, in addition to increasing our iron reserves, open the door to some regional development and the production of phosphorous, vanadium, alumina, and chromium as by-products. Since we are totally dependent on foreign suppliers for these by-products, their domestic production would contribute towards our self-sufficiency in minerals.

f) Canada has deposits of aluminum-bearing minerals containing 20 to 30% Al_2O_3. In addition to determining the available tonnages and grades of such materials, technology must be developed for recovering alumina from clays, shales, anorthosites, and other potential sources. The availability of such technology would ensure a long term supply of alumina for our extensive aluminum industry at a cost no higher than the cost of processing our domestic deposits.

g) Canada has low-grade deposits of chromium and manganese which cannot compete now with foreign sources. As in the case of alumina the technology for processing these ores should be developed as a hedge against high prices or shortages in the international market.

5.5 Conservation and Recycling of Mineral Resources and Materials

a) Although the mining, processing and utilization industries have a good record in their efficient use of energy there is still room for new technology to help solve energy supply problems. Increased use of hydrometallurgy to replace smelting would cause a change in energy use patterns from coal and uranium. In the steel industry, technology for reducing or eliminating oil and gas in blast furnaces and direct reduction operations by replacement with coal is needed. Improved efficiency in the fused salt electrolysis of aluminum should be pursued, and the potential for reducing the energy requirements in cement manufacturing is challenging.

b) As discussed above in 5.4, new technology is needed to recover more of our mineral resources in mining and processing operations.

c) The Canadian steel and foundry industries are dependent on foreign scrap for part of their supplies. New technology could contribute to replacing these imports with domestic scrap. (See also 5.4). A major problem is in the removal of trace impurities, such as copper, tin, cobalt, zinc, cadmium and lead, from the recycled scrap. Obviously, successful technology would increase the recycle ratio of the trace elements recovered as well as iron.

d) Technologies for producing high quality zinc and aluminum from non-ferrous automobile scrap, for sorting non-ferrous scrap on an alloy-identification basis, and for efficient removal of trace impurities from recycled copper are lacking.

e) Technologies for using more-abundant substitutes for less common metals, particularly where the recycle ratio is low or zero (the so-called dissipative uses) will be needed. This is an important concern even where the metal currently is considered to be in good supply, such as zinc used in galvanizing and paints.

f) Technology for making it possible to recover mineral waste mainly from mining, beneficiation, smelting and utilization operations used for example, as aggregate material, brick-making, insulation and road ballast could aid in conserving resources and in waste management (See section 5.2).

5.6 Continued Economic Viability of the Canadian Mineral Industry

a) A major component of the cost of the Canadian mineral system is in the transportation of ores, concentrates and other products from the mine site to the market. New materials for oil, gas and slurry pipelines, and new technologies for producing improved rail are but two areas where research could contribute to lower transportation costs.

b) Corrosion and wear of materials in the mining and processing of minerals contribute significantly to the cost of operation. Wear in grinding and continuous mining equipment, and corrosion in processing equipment provide for technological innovation.

c) Technology to permit a reduction in the unit cost of crushing and grinding is urgently needed. This is particularly important since these operations are high energy consumers.

d) On the basis of tonnage, open pit mining accounts for two-thirds of Canadian mining activity. Although much has been done there is still a potential for cost reduction through new technology.

e) The possibility of large quantities of nickel, copper and cobalt being recovered from nodules occurring in the ocean deeps means that Canada must take steps to ensure that the technology for either exploiting nodules or for producing the relevant minerals from domestic sources at competitive prices is available when needed.

f) The economic viability of the Canadian mineral-based industry as a whole the continued viability of mining communities now in existence, and the development and diversification of new mineral-based industries will depend heavily on solving the technological problems summarized in this report. For example, some operations may be curtained if we do not improve working environments and reduce the detrimental effects on the natural environment. New technology that will result in more efficient underground mining methods, the development of complex and sub-marginal ore bodies and improved recycling will promote and encourage exploration, mine development, and activity across the country.